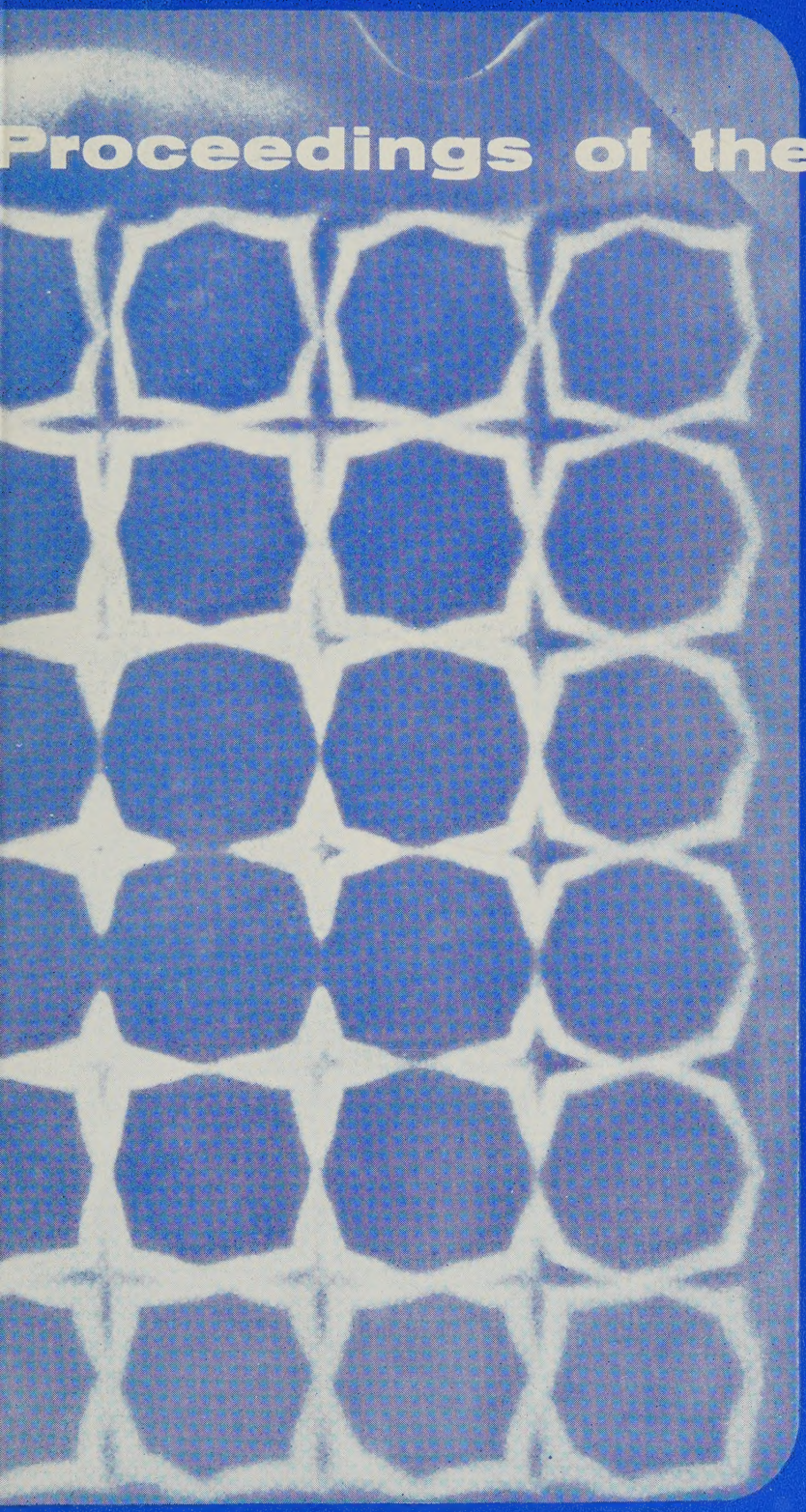
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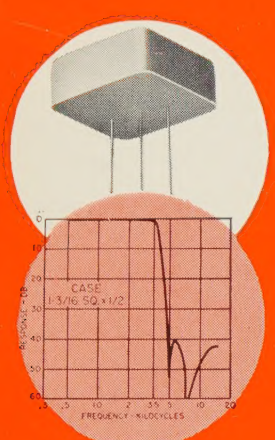
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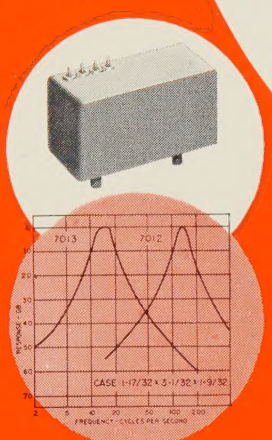
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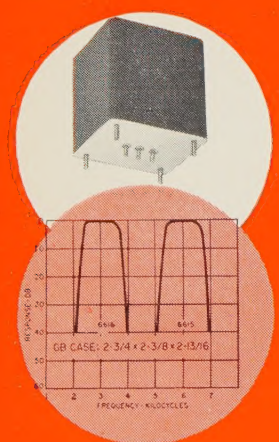


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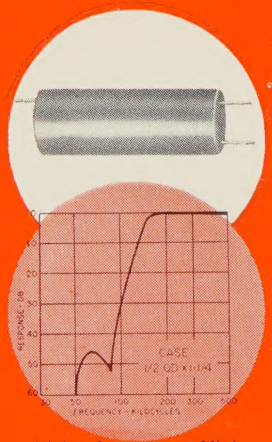


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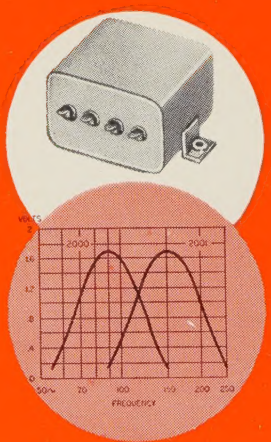
Almost thirty years of experience in the design and production of special filters have resulted in UTC being a first source for difficult units. Present designs incorporate a wide variety of core structures, winding methods, and capacitors to provide maximum performance, stability, and reliability. The units illustrated show a few of the thousands of specials produced by UTC, to customers' requirements, and only slightly indicate the possibilities in present special filter design. Range of frequencies on special units is from .1 cycles to 400 MC.



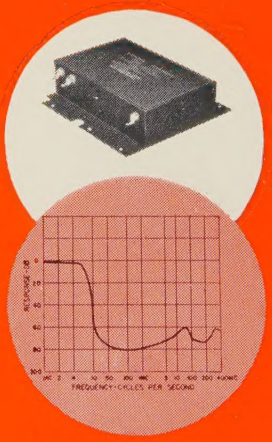
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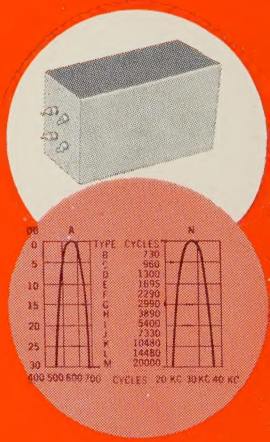
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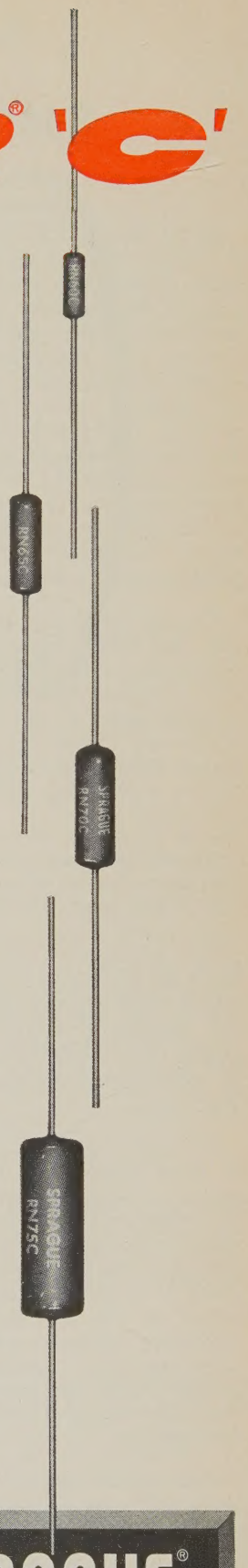
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Last month on this page we described some of the background leading to a currently active ionospheric space-research program.[1] This month Warren Offutt discusses some of the first generation flight equipment.

Sounding the Ionosphere — From Topside

PART II

In the fall of 1958, Dr. H. Booker of Cornell convened a special subcommittee of the Space Sciences Board to consider the feasibility of orbiting an ionosounder. The preliminary conclusions were encouraging, and the studies were continued through 1959 by Goddard Space Flight Center (NASA), National Bureau of Standards-Central Radio Propagation Laboratory (NBS-CRPL), Airborne Instruments Laboratory (AIL), and others. During 1959, the participating groups began theoretical and breadboard preparation for a flight test.

During the winter of 1959-1960, AIL and CRPL joined forces under NASA sponsorship to prepare and conduct a Topside Sounding experiment. Another group is also working with NASA on a Topside Sounder. The two designs differ in approach and will, we believe, provide data that complement each other.

The total program, a closely knit cooperative effort of scientists working with NASA scientists, consists of two major phases. First, a series of rocket probes launched this year will demonstrate the feasibility of the approaches selected and provide data on certain key ionospheric parameters. Second, during 1962, satellite ionosounders will be launched and operated for about a year.

The rocket probe designed at AIL to prove feasibility of the radar approach is shown in Figures 1 and 2. The completely transistorized systems operate at two frequencies and each transmitter has an RF power output of about 35 watts.[2] The topside echo received by the two-channel receiver modulates a telemetry transmitter. The signal from this transmitter is received on the ground, and processed to provide a film record of the data for manual analysis.

Although the useful life of the rocket probe will only be about 5 minutes (time from penetration of F_2 region to apogee of about 1000 km and return), we expect to get adequate engineering and scientific data to support the satellite flights next year. Two series of rocket flights are planned—one during quiet ionospheric conditions and one during disturbed ionospheric conditions.

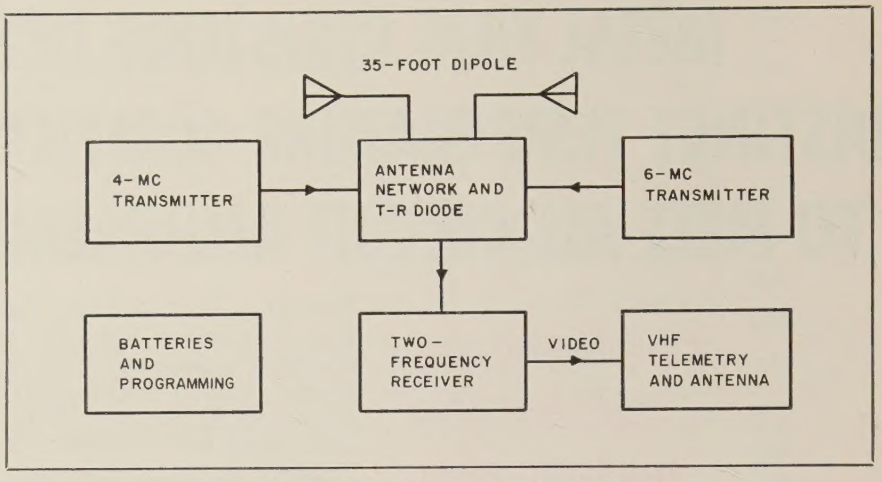


FIGURE 1. BLOCK DIAGRAM OF ROCKET PROBE SOUNDER

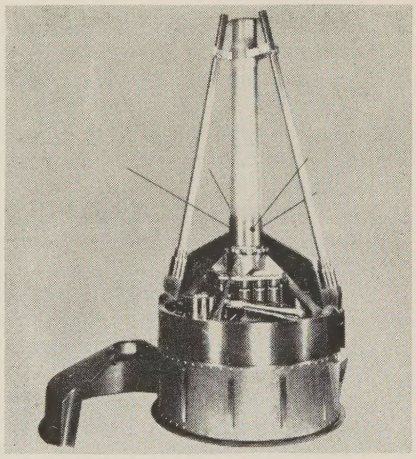


FIGURE 2. ROCKET PROBE IONOSOUNDER

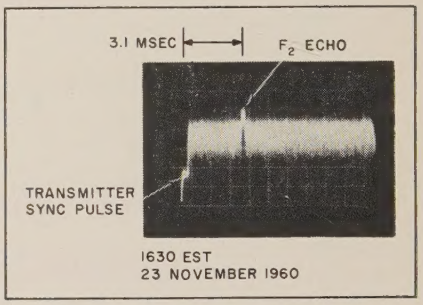


FIGURE 3. A-SCOPE DISPLAY OF 4-MC IONOSPHERE ECHO

Figure 3 shows an oscilloscope photograph obtained by operating one of the rocket payloads on the ground. Even though D-layer attenuation is troublesome when sounding from the ground, the echo from the 35-watt transmitter stands out clearly and indicates (4 Mc, in this case) an F_2 virtual height of 230 km. Similar or better signal-to-noise ratios are expected on the topside.

Next month we will conclude our description of this program with a discussion of the satellite equipment. We think you will find the discussion of the reliability problem, when one contemplates a one-year orbital lifetime, of particular interest.

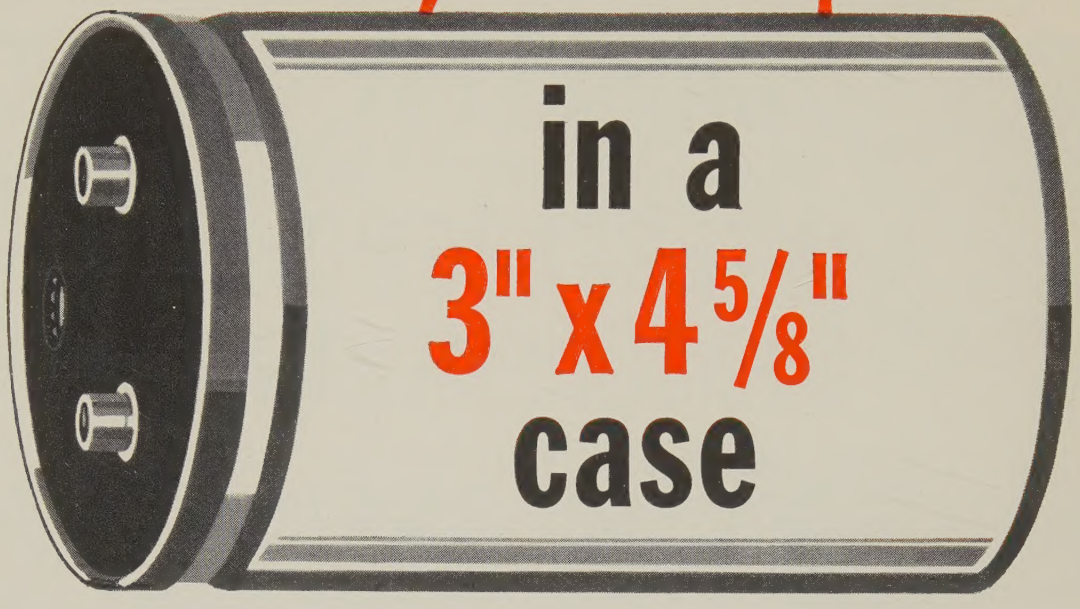
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[1] The work described here is being performed for NASA under Contract NAS 5-403.

[2] Transistorized RF power amplifiers having outputs well in excess of 100 watts are being operated in our Laboratory, but are not yet ready for flight.

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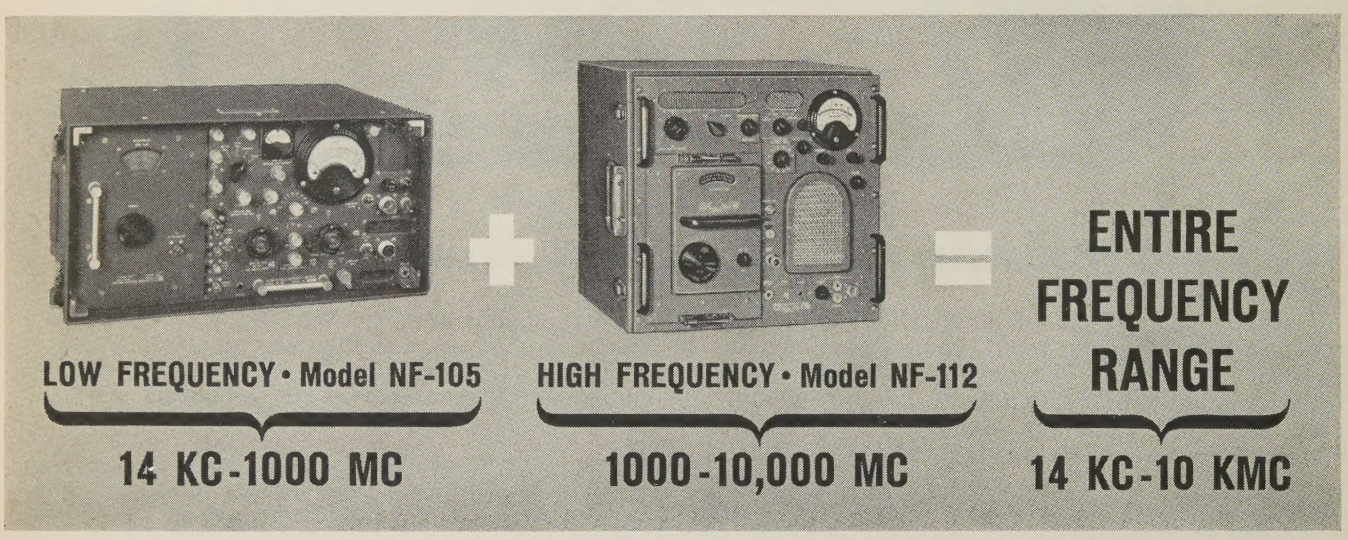
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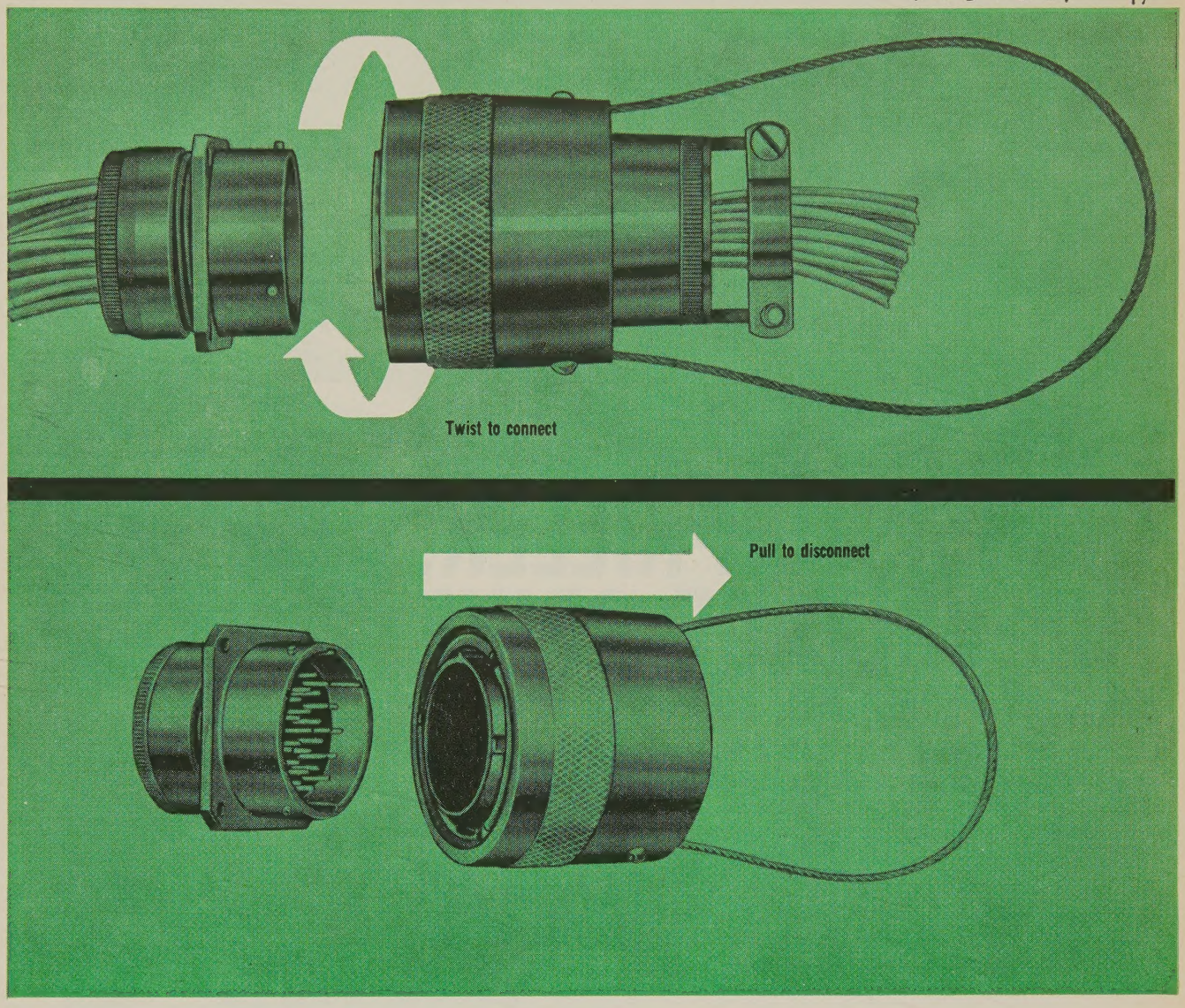
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This new Bendix® Pygmy® Electrical Connector uniquely combines positive coupling and pull-to-disconnect features. It is connected by a twist; disconnected either by hand or, remotely, by lanyard.

Complete intermateability with PT receptacles is achieved through use of standard Pygmy PT plug shells, five-key polarization, and three-point bayonet lock coupling. The "twist/pull" design assures inter-facial sealing and meets the performance requirements of MIL-C-26482.

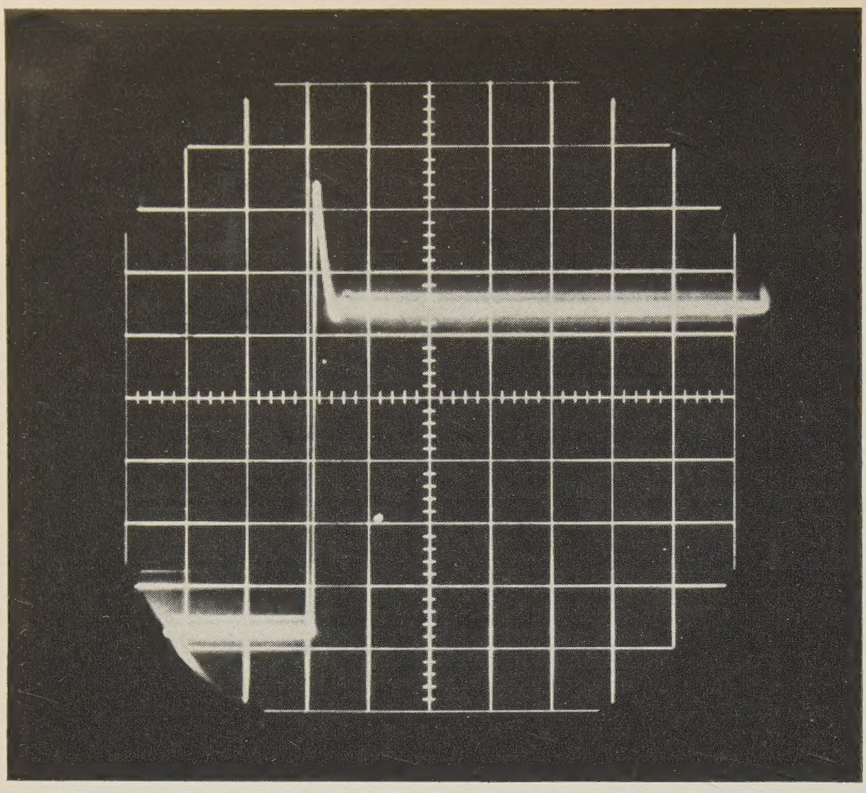
Resilient inserts assure extreme vibration resistance and provide support for size 20 or 16 gold-plated Pygmy contacts of either the solder or removable crimp type. Plating options for the aluminum shell components are: cadmium with an olive drab chromate after treatment, or alumilite hard anodic coating.

Write today for your copy of our informative technical bulletin SL-102, giving complete information on shell sizes and arrangements, as well as helpful design and dimensional data.

Scintilla Division
SIDNEY, NEW YORK

THE Bendix CORPORATION

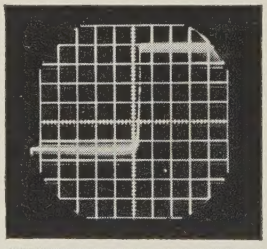
Canadian Affiliate: Aviation Electric, Ltd., 200 Laurentien Blvd., Montreal 9, Quebec. Export Sales & Service: Bendix International, 205 E. 42nd St., New York 17, N. Y.

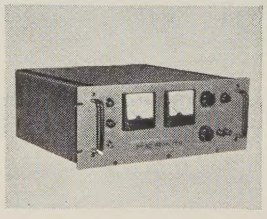


TRANSISTOR-KILLER: THE VOLTAGE SPIKE

TAMED BY PERKIN MTR DC POWER SUPPLIES

The "turn-on" transient above could destroy the transistors in your circuit in microseconds. Protect transistorized equipment against treacherous line and load transients with Perkin MTR tubeless power supplies. Combining the best of two solid-state regulation principles, they use magnetic amplifiers for high efficiency and transistors for instantaneous suppression of transients and ripple. No tubes, no moving parts, no trouble! Units sustain shorts and overloads indefinitely, resuming normal operation automatically. Ideal for continuous-duty and unattended operation. Prompt delivery anywhere.





HERE ARE JUST A FEW OF OUR MANY OFF-THE-SHELF UNITS
WRITE FOR COMPLETE CATALOG

Model No.	D.C. Output		Static Regulation		Dynamic Regulation		A.C. Input 60 cps, 1 Phase	Ripple RMS
	Volts	Amps	Line	Load	Line	Load		
MTR036-5	0-36	5	±10MV	±10MV	±10MV	±.2V	105-125V	1MV
MTR036-15	0-36	15	±10MV	±10MV	±10MV	±.2V	105-125V	1MV
MTR636-15	6-36	15	±25MV	±50MV	±25MV	±.75V	105-125V	5MV
MTR636-30	6-36	30	±25MV	±75MV	±25MV	±.85V	105-125V	5MV
MTR28-5	24-32	5	±0.1%	±0.1%	±0.1%	±.3V	105-125V	5MV
MTR28-10	24-32	10	±0.1%	±0.1%	±0.1%	±.4V	105-125V	2MV
MTR28-30	24-32	30	±0.1%	±0.1%	±0.1%	±.5V	105-125V	5MV

PERKIN
ELECTRONICS CORPORATION
345 Kansas Street, El Segundo, California ☐ SPring 2-2171

Representatives in Principal Cities

Visit Perkin at WESCON Booths 516-518

Meetings with Exhibits

● As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups, which include exhibits.

Δ

July 16-21, 1961

Fourth International Conference on Medical Electronics & Fourteenth Conference on Electrical Techniques in Medicine & Biology, Waldorf-Astoria Hotel, New York, N.Y.
Exhibits: Mr. Lewis Winner, 152 W. 42nd St., New York 36, N.Y.

August 22-25, 1961

Western Electronic Show and Convention (WESCON), Cow Palace and Fairmont Hotel, San Francisco, Calif.
Exhibits: Mr. Don Larson, WESCON, 701 Welch Road, Palo Alto, Calif.

September 6-8, 1961

National Symposium on Space Electronics & Telemetry, University of New Mexico Johnson Gym, Albuquerque, N.M.
Exhibits: Mr. C. H. Schmidt. 2901 Wisconsin N.E., Albuquerque, N.M.

October 2-4, 1961

Seventh National Communications Symposium, Hotel Utica & Utica Municipal Auditorium, Utica, N.Y.
Exhibits: Mr. R. E. Gaffney, General Electric Co., Light Military Electronics Dept., Utica, N.Y.

October 2-4, 1961

IRE Canadian Convention, Automotive Building, Exhibition Park, Toronto, Canada.
Exhibits: Business Manager, IRE Canadian Convention, 819 Yonge St., Toronto 7, Ontario, Canada.

October 9-11, 1961

National Electronics Conference, Hotel Sherman, Chicago, Ill.
Exhibits: Mr. Rudy Napolitan, National Electronics Conference, 228 N. LaSalle St., Chicago, Ill.

October 19-20, 1961

Sixth Annual Symposium on Electronics, Engineering and Education, Greensboro Coliseum, Greensboro, N.C.
Exhibits: Mr. H. G. Eidson, Jr., Dept. 8760, Charham Road Plant, Western Electric Co., Inc., Winston-Salem, N.C.

October 23-25, 1961

East Coast Conference on Aeronautical & Navigational Electronics, Lord Baltimore Hotel, Baltimore, Md.
Exhibits: Mr. Robert J. Henderson, Martin Company, Ground Support Equipment Dept., Baltimore, Md.

October 23-26, 1961

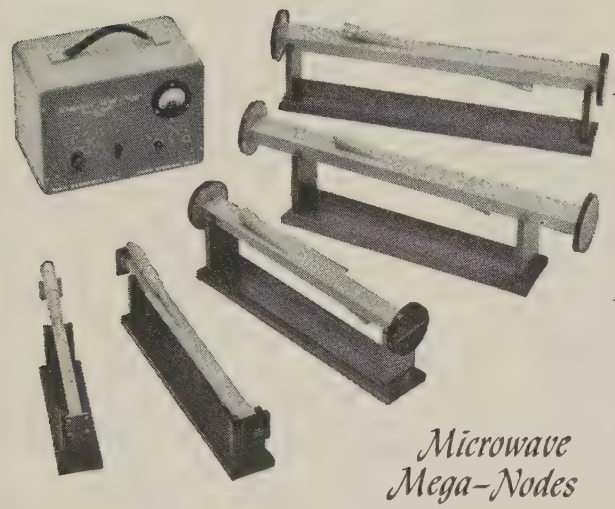
Eighth Annual Meeting, Professional Group on Nuclear Science (Aero-Space Nuclear Propulsion), Hotel Riviera, Las Vegas, Nevada
Exhibits: Mr. D. J. Knowles, Union Carbide Company, Oak Ridge National Lab., Oak Ridge, Tenn.

(Continued on page 10A)

KAY Precision Random Noise Generators



Mega-Node 3000



Microwave Mega-Nodes

1 kc to 1000 mc . . . *Therma-Node*

The **Therma-Node** is a basic noise source which provides extremely high accuracy by utilizing a basic noise generation technique — thermal noise from a heated resistive element.

- **Noise figure to 10 db**
- **Output impedance, 50 ohms unbalanced**
- **Accuracy ±0.1 db**
- **Operates from line or 24 V dc . . .**

2 — 1000 mc, Price **$550.00,** f.o.b. factory. (**$605.00** F.A.S., N. Y.)

1 kc — 300 mc, add **$135.00** (**$149.00** F.A.S., N. Y.)

1 mc to 3000 mc . . . *Mega-Node* 3000

The **Mega-Node 3000** is a calibrated random noise source providing output over a wide frequency and power range. It employs a coaxial-type noise diode with a tungsten filament as a temperature-limited noise generator.

- **Noise figure, 0-20 db**
- **Output impedance, 50 ohms unbalanced**
- **Accuracy ±.25 db below 250 mc, ±1.0 db below 2000 mc, ±1.5 db at 3000 mc**

Price **$790.00,** f.o.b. factory. (**$869.00** F.A.S., N. Y.)

3 mc to 500 mc . . . *Mega-Node* 403-A

The **Mega-Node 403-A** is a calibrated random noise source providing precise operation over a more limited frequency range at proportionately lower cost.

- **Noise figure, 0-19 db**
- **Output impedance, 50 ohms unbalanced**
- **Accuracy ±0.5 db**

Price **$375.00,** f.o.b. factory. (**$413.00** F.A.S., N. Y.)

1120 mc to 26,500 mc . . . *Microwave Mega-Nodes*

The **Microwave Mega-Nodes** are precision machined and plated waveguide fixtures, utilizing argon, fluorescent, or neon gas discharge tubes. Single power supply operates all units. (Power Supply Price, $125.00.) ($138.00 F.A.S., N. Y.)

- **Noise output of 15.8 ±.025 db for fluorescent tubes, 15.45 ±0.2 db for argon, 18.0 ±0.2 db for neon. Supplied with power cables and fittings**

Price **$175.00** up. (**$193.00** F.A.S., N. Y.)

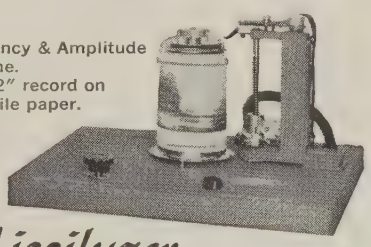
PERMANENT RECORDS

TIME

FREQUENCY

AUDIO SPECTRUM ANALYZERS

Frequency & Amplitude vs. Time.
4″ x 12″ record on facsimile paper.



KAY *Missilyzer* 5-15,000 cps

CAT. NO. 675

- **Two separate channels for simultaneous recording of two signals.**
- **Remote control of recording and reproducing channel selectors.**

The **Missilyzer** is a wider range spectrum analyzer providing two identical channels for simultaneous recording of two related signals. Built-in fast acting relays permit rapid automatic remote control.

Price **$2,950.00,** f.o.b. factory. (**$3,245.00** F.A.S., New York.)

KAY *Sona-Graph* MODEL RECORDER

CAT. NO. 662-A

- **85 — 12,000 cps**
- **Easily stored, permanent or reusable magnetic disc recording.**

The **Sona-Graph Model Recorder** is an audio spectrograph for sound and vibration analysis. Unit provides four permanent, storable records of any sample of audio energy in the 85-12,000 cps range.

Price **$2,950.00,** f.o.b. factory. (**$3,245.00** F.A.S., New York.)

PRECISION HIGH FREQUENCY *Attenuators*



ROTARY MODELS

- Digital Readout
- 0 — 119 db

TOGGLE-SWITCH MODELS

- Up to 101 db
- Fixed 0 or 10* db insertion loss

50, 70 or 90 ohm impedance
High-Frequency, Precision Teflon & Silver Switches
1% Carbon Film Resistors
Fully Shielded Units

	TOGGLE SWITCH MODELS		ROTARY MODELS
	MOD. 20 SERIES	MOD. 30 SERIES	MODEL 40 SERIES
SWR	1.2 : 1 MAX UP TO 250 MC 1.4 : 1 MAX 250 TO 500 MC		
MIN INSERTION*	0.1 db at 250 mc; 0.2 db at 500 mc		
ACCURACY	AT FULL ATTENUATION: 0.5 db at 250 mc, 1.2 db from 250 to 500 mc.	AT FULL ATTENUATION: 0.9 db at 250 mc, 2.0 db from 250 to 500 mc.	
PRICE:			
f.o.b. factory	$75. ($79.*)	$110.	$250.
F.A.S. N. Y.	$83. ($87.*)	$121.	$275.

KAY

ELECTRIC COMPANY

MAPLE AVENUE • PINE BROOK, N. J.

DEPT. I-7 CAPITAL 6-4000

model 317



NEW Ballantine VTVM measures 300 μV to 300 V

Price: $445.
(With probe $495)

at Frequencies 10 cps to 11 Mc

FEATURES: ● Accuracy is % of reading anywhere on scale at any voltage ● Five inch mirror-backed voltage scales of 1 to 3 and 3 to 10, each with 10% overlap; 0 to 10 db scale ● Use as a sensitive null detector 5 cps to 30 Mc ● Use as a stable 60 db wideband amplifier, 2.5 volts max. output ● Cathode follower probe has a voltage range of 300 μV to 300 mV, and a high input impedance ● Instrument is average responding type. ● Effect of line transients nil ● Available in portable model shown or in 19 inch rack version.

SPECIFICATIONS:

VOLTAGE: 300 μV to 300 V.
FREQUENCY: 10 cps to 11 Mc (As a null detector, 5 cps to 30 Mc).

ACCURACY: % of reading anywhere on scale at any voltage. 20 cps to 2 Mc — 2%; 10 cps to 6 Mc — 4%; 10 cps to 11 Mc — 6%.

SCALES: Voltage, 1 to 3 and 3 to 10, each with 10% overlap. 0 to 10 db scale.

INPUT IMPEDANCE: With probe, 10 megohms shunted by 7 pF. Less probe, 2 megohms shunted by 11 pF to 24 pF.

AMPLIFIER: Gain of 60 db ± 1 db from 6 cps to 11 Mc; output 2.5 volts.

POWER SUPPLY: 115/230 V, 50 — 400 cps, 70 watts.

DIMENSIONS (Inches): Portable, 13 h x 7½ w x 9½ d. Rack, 8¾ h x 19 w x 8½ d.

WEIGHT: 17 pounds, portable or rack models. Approximately 34 pounds shipping weight.

Write for brochure giving many more details

— Since 1932 —

BALLANTINE LABORATORIES INC.

Boonton, New Jersey

CHECK WITH BALLANTINE FIRST FOR LABORATORY AC VACUUM TUBE VOLTMETERS, REGARDLESS OF YOUR REQUIREMENTS FOR AMPLITUDE, FREQUENCY, OR WAVEFORM. WE HAVE A LARGE LINE, WITH ADDITIONS EACH YEAR. ALSO AC DC AND DC AC INVERTERS, CALIBRATORS, CALIBRATED WIDE BAND AF AMPLIFIER, DIRECT-READING CAPACITANCE METER, OTHER ACCESSORIES. ASK ABOUT OUR LABORATORY VOLTAGE STANDARDS TO 1,000 MC.

Meetings with Exhibits

(Continued from page 8A)

October 26-27, 1961

Electronic Techniques in Medicine & Biology Conference, University of Nebraska, Omaha, Neb.

Exhibits: Mr. Harold G. Beenken, University of Nebraska, College of Medicine, 428 Dewey Avenue, Omaha, Neb.

November 13-16, 1961

Conference on Magnetism & Magnetic Materials, Hotel Westward Ho, Phoenix, Ariz.

Exhibits: Mr. John L. Whitlock, 253 Waples Mill Road, Oakton, Va.

November 14-16, 1961

Mid-America Electronics Conference (MAECON), Hotel Muehlebach, Kansas City, Mo.

Exhibits: Mr. Felix A. Spies, Bendix Corporation, P.O. Box 1159, Kansas City 41, Mo.

November 14-16, 1961

Northeast Research and Engineering Meeting (NEREM), Boston Commonwealth Armory, Boston, Mass.

Exhibits: Miss Shirley Whitcher, IRE Boston Office, 313 Washington St., Newton, Mass.

November 30-December 1, 1961

PGVC Annual Meeting, Hotel Raddison, Minneapolis, Minn.

Exhibits: Mr. Harold T'Kach, Mobile Engineering, Inc., 620 North Sixth St., Minneapolis, Minn.

December 3-7, 1961

Eastern Joint Computer Conference, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Dr. Jack Moshman, Capitol Radio Engineering Institute, 1200 Jefferson Davis Highway, Arlington 2, Va.

January 9-11, 1962

8th National Symposium on Reliability & Quality Control, Statler-Hilton Hotel, Washington, D.C.

Exhibits: Mr. M. P. Smith, Minneapolis-Honeywell Regulator Co., Aeronautical Div., 13350 U. S. Highway 19, Saint Petersburg, Fla.

February 7-9, 1962

3rd Winter Convention on Military Electronics, Ambassador Hotel, Los Angeles, Calif.

Exhibits: IRE Los Angeles Office, 1435 S. La Cienega Blvd., Los Angeles, Calif.

Δ

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.

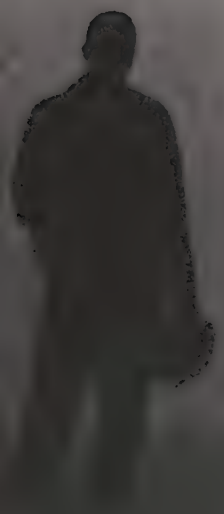
PIONEERING

AT BELL TELEPHONE LABORATORIES

In such an open field as this Dr. Karl Jansky of Bell Laboratories opened the way to radio astronomy. His search for a mysterious source of radio noise led him—and us—to the stars for our answer.

Today Bell scientists continue their pioneering in many fields—among them the transmission of human voices on beams of coherent light. Bell Laboratories' revolutionary Optical Maser foreshadows the use of light as a whole new medium of telephone, TV and data communications.

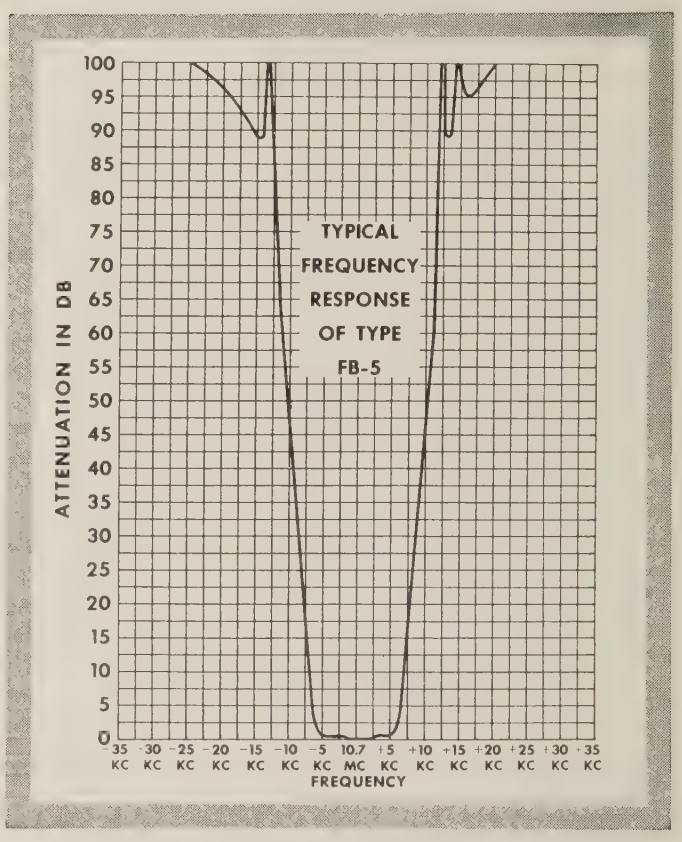
These are but two of the many fundamental advances which have come from breaking fresh ground at the world center of communications research and development.

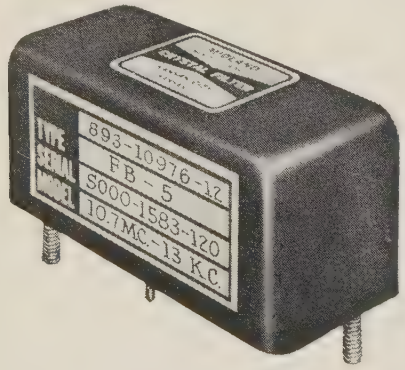


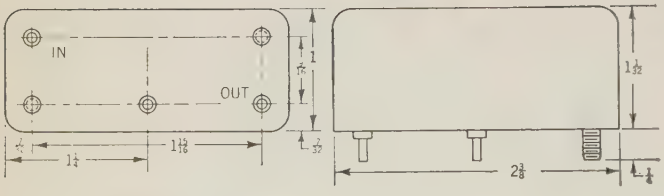
HAVE NARROW-BAND FILTER PROBLEMS?

A Midland "off the shelf" miniature crystal filter may be your answer to conserving space and reducing material and manufacturing costs

The Type FB Series is a group of hermetically sealed, eight-crystal, narrow-band filters that provide bandwidths in the range of 2 KC to 30 KC @ 6db, with a center frequency of 10.7 MC. Miniature in size, they are designed to operate in the environmental temperature range of −55°C to +90°C, with an insertion loss of 4db max. and an inband ripple of .8db max. Their specified ultimate rejection is 105db min. The type FB narrow-band crystal filter is ideally suited for design in two-way communication systems, telemetry systems, electronic instrumentation equipment and other applications where small fractional bandwidth filtering plus a high degree of selectivity and temperature stability is required. For further application information, write for ENGINEERING BULLETIN NO. NBS-102.







Specifications

	FB-2	FB-3	FB-5	FB-6	FB-8	FB-10
Center Freq.*	10.7±200 CPS	10.7±225 CPS	10.7±375 CPS	10.7±425 CPS	10.7±750 CPS	10.7±1 KC
BW @ 6 db Min.	2 KC	5 KC	13 KC	15 KC	20 KC	30 KC
BW @ 60 db Max.	3.6 KC	9 KC	23 KC	27 KC	36 KC	53 KC
60 db/6 db BWR Max.	1.8	1.8	1.8	1.8	1.8	1.8
BW @ 80 db Max.	4.5 KC	11.3 KC	26 KC	31 KC	41 KC	60 KC
Ultimate Rejection Min.	105 db	105 db	105 db	105 db	105 db	105 db
Req. Source/Load Resistance (R_o)	130 ohms	330 ohms	1 K ohms	1 K ohms	1.3 K ohms	2 K ohms
Inband Ripple Max.	.8 db	.8 db	.8 db	.8 db	**.8 db	***.8 db
Insertion Loss Max.	4 db	4 db	4 db	4 db	4 db	4 db
BW @ 1 db Min.	1.5 KC	3.8 KC	10 KC	11.5 KC	15 KC	21 KC

* Center freq. is the arithmetic mean of the frequencies at 6 db.
** 1.5 db max. ripple at the operating temperature extremes.
*** 1.8 db max. ripple at the operating temperature extremes.

Operating Temp. Range: −55°C to +90°C
Shock: 200 g
Vibration: 15 g to 2 KC
Max. Input Level: +10 dbm

Midland

MANUFACTURING COMPANY, 3155 Fiberglas Rd., Kansas City 15, Kansas
WORLD'S LARGEST PRODUCERS OF QUARTZ CRYSTALS
DIVISION, PACIFIC INDUSTRIES, INCORPORATED

MID 3-61

New

CORNING CYFM CAPACITOR has reliability you can see

You get total protection against environment for less money than ever before

The new Corning CYFM capacitor gives you reliability at a markedly lower cost than that of any like capacitor.

The CYFM goes far beyond MIL-C-11272B specs. It has proved its performance through more than 3,000,000 hours of testing. It took a 50-day MIL moisture test and a 96-hour salt spray test with no measurable effects. We stopped testing only when it became evident that no more significant data could be developed. The CYFM went through other tests, with solvents, fluxes, boiling salt, and steam, to make sure it is the most completely sealed capacitor you can buy.

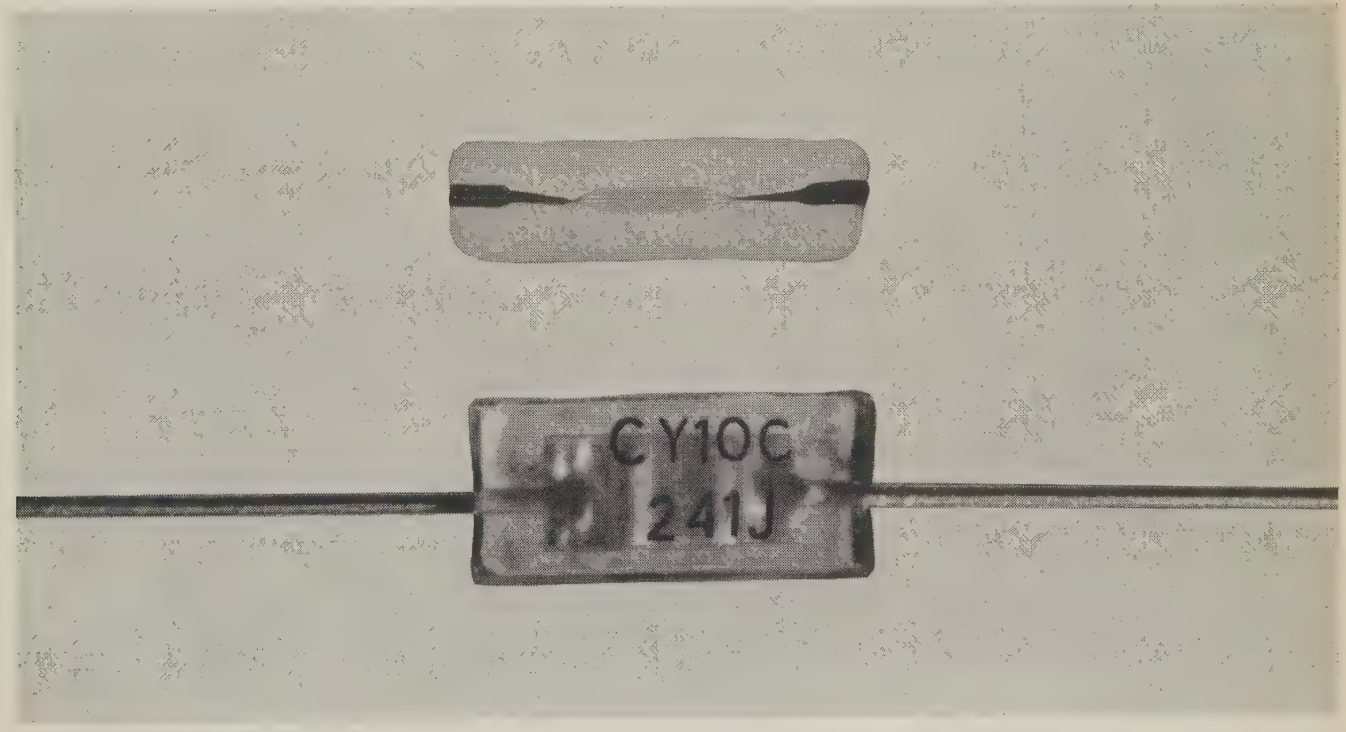
You'll see why the CYFM can take such torture when you check its design. We stack alternate layers of stable ribbon glass and aluminum foil. Then we weld the foils to the bead-terminal assembly, which has a glass bead sealed to the Dumet wire lead. With heat and pressure, the entire capacitive element is frozen in glass for complete protection against environment and for structured protection against physical shock.

True glass-to-metal seals at the weld area and along the leads bar moisture. The seal of the leads to the glass shifts stresses from the leads to the entire monolithic unit, guarding the capacitance area. Of course, you get electrical performance to match this environmental stability, since the CYFM has our glass-foil capacitor construction.

The CYFM is machine made . . . each capacitor is the same as every other, to give you uniformity which hand production cannot match.

You can get immediate delivery on the CYFM in two types. The CYFM-10 gives capacitance values from 1 to 300 *pf*. The CYFM-15 provides values from 220 to 1200 *pf*.

For the rest of the story on this capacitor, send for our data sheet. Write to Corning Glass Works, 542 High Street, Bradford, Pa.



This is the CYFM capacitor. 6 times actual size. The dark areas between the ends of the glass and the capacitance element are your visual proof of the complete glass-to-metal seal.

CORNING ELECTRONIC COMPONENTS

CORNING GLASS WORKS, BRADFORD, PA.

IRE News and Radio Notes

Current IRE Statistics

(As of May 31, 1961)

Membership—88,647
Sections*—110
Subsections*—30
Professional Groups*—28
Professional Group Chapters—292
Student Branches†—208

* See this issue for a list.
† See June, 1961, issue for a list.

Calendar of Coming Events and Author's Deadlines*

1961

1961 Conv., British Institution of Radio Engineers, Univ. of Oxford, July 5–8.

Colorado State Univ., 4th Ann. Institute in Technical and Industrial Communications, July 10–14.

4th Int'l. Conf. On Medical Electronics & 14th Conf. on Elec. Techniques in Medicine & Biology, Waldorf-Astoria Hotel, New York, N. Y., July 16–21.

WESCON, Cow Palace, San Francisco, Calif., Aug. 22–25.

3rd Int'l. Conf. on Analog Computation, Belgrade, Sept. 4–9.

1961 Nat'l. Symp. on Space Electronics and Telemetry, Univ of N. M., Albuquerque, N. M., Sept. 6–8.

Joint Nuclear Instrumentation Symp., North Carolina State College, Raleigh, N. C., Sept. 6–8.

Int'l. Conf. on Electrical Engrg. Education Syracuse Univ., Adirondacks, N. Y., Sept. 6–13.

IRE Conf. on Technical-Scientific Communications, Bellevue Stratford Hotel, Philadelphia, Pa., Sept. 13–15.

9th Ann. Engrg. Management Conf., Roosevelt Hotel, New York, N. Y., Sept. 14–16.

10th Ann. Industrial Electronics Symp., Bradford Hotel, Boston, Mass., Sept. 20–21.

CISPR, Univ. of Pennsylvania, Philadelphia, Oct. 1–6.

7th Nat'l. Communications Symp., Utica, N. Y., Oct. 2–4.

IRE Canadian Electronics Conf., Automotive Bldg., Exhibition Park, Toronto, Canada, Oct. 2–4.

11th Ann. Broadcast Symp., Willard Hotel, Washington, D. C., Oct. 6–7.

Nat'l. Electronics Conf., Int'l. Amphitheatre, Chicago, Ill., Oct. 9–11.

ARS Space Flight Rept. to the Nation, New York Coliseum, New York, N. Y., Oct. 9–15.

5th Nat'l. Symp. on Engrg. Writing and Speech, Kellogg Ctr. for Continuing

* DL = Deadline for submitting abstracts.

(Continued on page 15A)

Nominations for 1962 IRE Officers and Directors

At its April 28, 1961, meeting, the IRE Board of Directors voted to place the following nominees for officers and delegates-directors on the ballot, to be subm tted to voting members by September 1, 1961. They are as follows:

President, 1962—Patrick E. Haggerty
Vice President, 1962 (residing in North America)—T. A. Hunter
Vice President, 1962 (residing elsewhere than in North America)—A. M. Angot
Delegates-at-large/Directors-at-large, 1962–1964 (two to be elected)—Rawson Bennett, Britton Chance, G. K. Teal, and G. A. Woonton
Regional Delegates/Regional Directors, 1962–1963 (one to be elected in each Region):
Region 1—W. J. Kuehl and F. K. Willenbrock
Region 3—M. R. Briggs, R. G. Fellers, C. H. Hoeppner, and E. L. White
Region 5—Kenneth Backman, W. B. Bruene, and A. J. Ebel
Region 7—B. S. Angwin and D. K. Reynolds

According to Article VIII, Section 2 of the IRE Constitution, nominations by petition for any of the above offices may be made by letter to the Board of Directors setting forth the name of the proposed candidtate and the office for which the candidate is desired to be nominated, provided such letter is received at the general offices of the IRE before noon on the Friday prior to August 15, 1961. Such a petition shall be signed by at least one per cent of the total number of voting members as listed in the official membership records of the IRE at the end of the previous year, but in no case shall the number be less than one hundred.

Program Sessions Announced For Medical Electronics Conference

The Fourth International Conference on Medical Electronics, combined with the Fourteenth Annual Conference on Electrical Techniques in Medicine and Biology, will be held at the Waldorf-Astoria Hotel, New York, N. Y., on July 16–21, 1961. The Conference is sponsored by the Joint Executive Committee on Medicine and Biology of the IRE, the AIEE, and the ISA. It is being held under the auspices of the International Federation for Medical Electronics, and is organized by the IRE through the Professional Group on Bio-Medical Electronics.

Approximately 270 papers have been accepted by the Program Committee for presentation. The program will be organized into simultaneous sessions. Papers are to be presented in English, French, German, and Russian, with two sessions per day translated. In addition to the scientific sessions there will be approximately 75 commercial exhibits.

A program of tours and visits will be arranged to the Columbia-Presbyterian Medical Center, Coumbia University, Columbia University Plainsboro Nuclear Reactor, Veterans Administration Hospital, Brookhaven National Laboratories, Prudential Insurance Company of America Computer Center, and the IBM Research Center. A ladies' program of entertainment and sightseeing is planned.

The technical sessions are as follows:

Monday Morning, July 17: Registration

Monday Afternoon: 1) Electrical Techniques—Obstetrics, Gynecology; 2) Computer Diagnosis; 3) Electronic Images and Scanning Systems; 4) Data Processing

Monday Evening: Workshop (Informal Discussions)—"Perspectives in Bio-Medical Engineering," O. H. Schmitt

Tuesday Morning, July 18: 1) Mathematical Models; 2) Recording, Storage, and Retrieval of Data I; 3) Magnetic Resonance and Electrical Impedance; 4) Electrical Techniques—Obstetrics, Gynecology

Tuesday Afternoon: 1) Biological Control Systems I; 2) Sound and Related Techniques; 3) Neurology, Ophthalmology and Otology; 4) Determination of Circulatory Parameters I

Tuesday Evening: Workshop—"Compusters," T. Sandel; "Acoustics," J. Reid and W. Fry; IFME Council Meeting

Wednesday Morning, July 19: 1) Gastroenterology I; 2) Recording, Storage, and Retrieval of Data II; 3) Biological Control Systems II; 4) Instrumentation I (Electrophysiology)

Wednesday Afternoon: 1) Instrumentation II (Telemetry); 2) Gastroenterology II; 3) Biological Control Systems III; 4) Determination of Circulatory Parameters II

Wednesday Evening: IFME Plenary Meeting

Thursday Morning, July 20: 1) Biological Effects of Microwaves I (Atherman Aspects); 2) Theory of Neural Functions and Organization; 3) Electrophysiological Instrumentation I; 4) Cardiac Output and Pacemakers

Thursday Afternoon: 1) Determination of Circulatory Parameters III; 2) Biological Effects of Microwaves II (Thermal Aspects); 3) Electrophysiological Instrumentation II; 4) Cardiac Instrumentation

Thursday Evening: Workshop—"Biological Effects of Microwaves"; "Recording, Storage, and Retrieval of Data," G. Webb and R. Schoenfeld; "Electrocardiography," D. Geselowitz; Banquet

Friday Morning, July 21: 1) Radiology Technology I; 2) Biological Effects of Microwaves III; 3) Electrocardiography; 4) Instrumentation III

Friday Afternoon; 1) Heart Sounds and Pressure; 2) Radiology Technology II; 3) Education and Documentation; 4) Instrumentation IV

Friday Evening: Conference Committee Meeting

Call for Papers For Conference on Nonlinear Magnetics

The 1961 Special Technical Conference on Nonlinear Magnetics will be held on November 6–8 at the Statler-Hilton Hotel in Los Angeles, Calif. Dr. Ted Bernstein, Chairman of the Technical Program Committee, has announced that the closing date for submission of Conference papers has been extended to August 1, 1961.

For further details concerning this Conference, which is being cosponsored by the American Institute of Electrical Engineers and the IRE Professional Groups on Electronic Computers and Industrial Electronics, contact: Dr. Ted Bernstein, Space Technology Labs., P.O. Box 95001, Los Angeles 45, Calif.

Magnetism Conference Plans Near Completion

More than 1000 scientists and engineers are expected to attend the seventh annual International Conference on Magnetism and Magnetic Materials, which will be held in the Thunderbird Room of the Westward Ho Hotel, Phoenix, Ariz., on November 13–16, 1961.

Dr. P. B. Myers, staff scientist for the Semiconductor Products Division of Motorola, Inc., and local Chairman of the Conference, said that the invited speakers include representatives from Russia, Japan, England, and France.

As in the past, the Conference will emphasize the value of bringing together for discussion those interested in basic theory and practical application of magnetism. Papers on basic theoretical and experimental investigations, potential engineering applications, and apparatus and techniques which utilize recent advances in magnetism are being solicited. Authors should submit abstracts, by August 18, 1961, to Dr. F. E. Luborsky, General Electric Co., Research Lab., P. O. Box 1088, Schenectady, N. Y.

Also, as in past years, an exhibit of magnetic products and instrumentation is being sponsored by the Conference, Dr. Myers said.

The Conference is sponsored jointly by the AIEE and the American Institute of Physics in cooperation with the Office of Naval Research, the IRE, and the Metallurgical Society of the AIME.

Dr. R. L. Bickford, scientist with the IBM Research Laboratories, Yorktown Heights, N. Y., is General Chairman of the Conference.

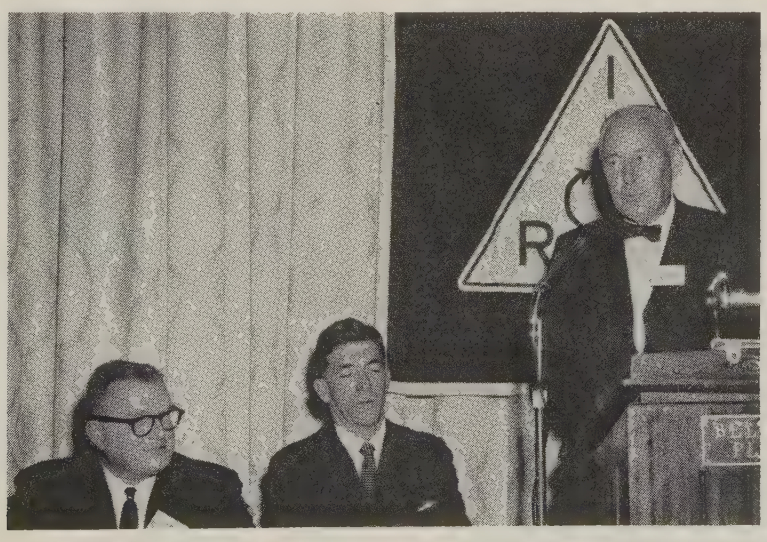
Aerospace Symposium Announces Session Topics

The International Symposium on Aerospace Nuclear Propulsion, which will be held in the Riviera Hotel, Las Vegas, Nev., on October 24–26, 1961, recently announced its tentative technical program session topics as follows:

1) Program Review: ROVER, PLUTO, ANP, SNAP
2) Advance Propulsion Systems (ION, ORION, etc.)
3) Engine Characteristics and Dynamics
4) Recent Advances in Nucleonic Instrumentation
5) Engine Simulation and Control
6) Non-Nuclear Instrumentation for Aerospace Propulsion
7) Effects of Nuclear Radiation on Controls and Instruments
8) Nuclear Instrumentation for Aerospace Propulsion

Dr. G. T. Seaborg, Chairman of the U. S. Atomic Energy Commission, will be the Honor Speaker at a luncheon during the Symposium. Also featured during this three-day meeting will be a tour to the Jackass Flats Facilities at the Nevada Test Site where Projects ROVER and PLUTO are being carried on.

For information concerning submission of papers to the Symposium, contact: P. M. Uthe, Lawrence Radiation Lab., Livermore, Calif.



(Left to *right)*: Sven Dodington, Chairman of the New York Metropolitan Chapter of the IRE Professional Group on Aerospace and Navigational Electronics, and also Vice President and Technical Director of ITT Laboratory; Najeed Hallaby, newly-appointed Administrator of the FAA and principal speaker at the annual luncheon of the PGANE; and Dr. L. V. Berkner, President of the IRE. Dr. Berkner was a guest at the PGANE luncheon on March 21, 1961, during the IRE International Convention, and gave a short talk to approximately 300 members of the PGANE who were present in the Baroque Room of the Belmont Plaza Hotel in New York, N. Y.

Calendar of Coming Events and Author's Deadlines*

(Continued from page 14A)

Education, Michigan State Univ., East Lansing, Oct. 16–17. (DL*: July 15, J. Chapline, Philco Corp., Computer Div., 3900 Welsh Rd., Willow Grove, Pa.)

Int'l Conf. on Ionization of the Air, Franklin Inst., Philadelphia, Pa., Oct. 16–17.

6th Ann. North Carolina Section Symp., Greensboro Coliseum, Greensboro, N. C., Oct. 19–20.

East Coast Conf. on Aerospace & Navigational Electronics, Lord Baltimore Hotel, Baltimore, Md., Oct. 23–25.

URSI-IRE Fall Mtg., Univ. of Texas, Austin, Oct. 23–25.

PGNS 8th Ann. Mtg., Hotel Riviere, Las Vegas, Nev., Oct. 23–26. (DL*: July 1, P. M. Uthe, Univ. of Calif., Lawrence Radiation Lab., Box 808, Livermore, Calif.)

Symp. on Instrumentation Facilities for Biomedical Res., Sheraton Fontenelle Hotel, Omaha, Neb., Oct. 26–27.

1961 Electron Devices Mtg., Sheraton-Park Hotel, Washington, D. C., Oct. 26–28. (DL*: Aug. 1, Dr. I. M. Ross, Bell Telephone Labs., Inc., Murray Hill, N. J.)

Radio Fall Mtg., Hotel Syracuse, Syracuse, N. Y., Oct. 30–31.

6th Ann. Special Technical Conf. on Nonlinear Magnetics, Statler Hilton Hotel, Los Angeles, Calif., Nov. 6–8. (DL*: Aug. 1, T. Bernstein, Space Technology Labs., Inc., P. O. Box 95001, Los Angeles, Calif.)

Conf. on Electrically-Exploded Wires, Kenmore Hotel, Boston, Mass., Nov. 13–14.

7th Ann. Conf. on Magnetism and Magnetic Materials, Hotel Westward Ho, Phoenix, Ariz., Nov. 13–16. (DL*: Aug. 18, F. E. Luborsky, GE Co., Res. Lab., P. O. Box 1088, Schenectady, N. Y.)

NEREM, Boston, Mass., Nov. 14–16.

Electronic Systems Reliability Symp., Linda Hall Library Auditorium, Kansas City, Mo., Nov. 14 (DL*: Sept. 1, Dr. A. Goldsmith, Wilcox Electric, Kansas City, Mo.)

PGVC Conf., Hotel Radisson, Minneapolis, Minn., Nov. 30–Dec. 1.

Eastern, Joint Computer Conf., Sheraton-Park Hotel, Washington, D. C., Dec. 12–14.

1962

8th Nat'l. Symp. on Reliability and Quality Control, Statler Hilton Hotel, Washington, D. C., Jan 9–11. (DL*: May 15, 1961, E. F. Jahr, IBM Corp., Owego, N. Y.)

3rd Winter Conv. on Military Electronics, Ambassador Hotel, Los Angeles, Calif., Feb. 7–9.

8th Scintillation and Semiconductor Counter Symp., Shoreham Hotel, Washington, D. C., Mar. 1–2.

* DL = Deadline for submitting abstracts.

Professional Group News

At its meeting on April 27, 1961, the IRE Executive Committee approved the following new chapters: PG on **Bio-Medical Electronics**—Twin Cities Chaper; PG on **Component Parts**—Houston Chapter; PG on **Radio Frequency Interference**—Chicago Chapter.

IRE Canadian Conference To Meet in October

The 1961 IRE Canadian Electronics Conference, which will be held at the Automotive Building, Exhibition Park, Toronto, from October 2–4, will feature exhibits of the latest equipment and techniques by over 170 Canadian, U. S., and overseas companies. Also, over eighty papers and panel discussions conducted by leading experts will deal with the most important technical and business developments in the industry. The Conference theme is "Progress Through Electronics." It is felt that the Conference provides not only a vehicle for dissemination of technical information, but an excellent opportunity for business and professional men to evaluate current and potential applications of electronic devices and techniques in every phase of industry, commerce, medicine, and defense.

The Automotive Building, located ten minutes from Toronto, will again be the Conference site. The facilities include a 120,000 square foot exhibit hall, technical meeting halls on the second floor, a restaurant and lounge, and ample parking space.

Among the branches of industry to be represented at the Conference will be the following:

Components
Antennas
Audio
Broadcast Transmission Systems
Aeronautical and Navigational Aids
Tubes
Transistors
Computers
Nuclear Industry Supplies and Services
Instrumentation
Medical Electronics
Electron Devices
Industrial Eelctronics
Radio Telemetry and Remote Control
Vehicular Communications
Ultrasonics Engineering
Production Machines
Instruments and Equipment
Laboratory Apparatus
Measurement Equipment
Packaging
Education

The Conference is now scheduled on a biennial basis. This year, over 9000 engineers, technicians, armed service personnel and business men are expected to attend.

For information concerning registration or application for exhibit space, contact: The Canadian Electronics Conference, 1819 Yonge St., Toronto 7, Canada.

Call for Papers

1962 IRE International Convention

March 26–29, 1962

Waldorf-Astoria Hotel and the New York Coliseum, New York, N. Y.

Prospective authors are requested to submit all of the following information by:

October 20, 1961

1. 100-word abstract *in triplicate*, title of paper, name and address
2. 500-word summary *in triplicate*, title of paper, name and address
3. Indicate the technical field in which your paper falls:

Aerospace & Navigation Electronics
Antennas & Propagation
Audio
Automatic Control
Bio-Medical Electronics
Broadcast & Television Receivers
Broadcasting
Circuit Theory
Communications Systems
Component Parts
Education
Electron Devices
Electronic Computers
Engineering Management
Engineering Writing & Speech
Human Factors in Electronics
Industrial Electronics
Information Theory
Instrumentation
Microwave Theory & Techniques
Military Electronics
Nuclear Science
Product Engineering & Production
Radio Frequency Interference
Reliability & Quality Control
Space Electronics & Telemetry
Ultrasonic Engineering
Vehicular Communications

Note: Only original papers, not published or presented prior to the 1962 IRE International Convention, will be considered. *Any necessary military or company clearance of papers must be granted prior to submission.*

Address all material to: Dr. Donald B. Sinclair, Chairman
1962 Technical Program Committee
The Institute of Radio Engineers, Inc.
1 East 79 Street, New York 21, N. Y.

PGVC Announces 12th Annual Conference

The 12th Annual Conference of the Professional Group on Vehicular Communications will be held at the Hotel Radisson in Minneapolis, Minn., on November 30 and December 1, 1961. The Conference theme is "The Unseen Future of Vehicular Communications."



The above photograph was taken at the April 20, 1961, meeting of the Pasadena Subsection of the Los Angeles Section of the IRE. (*Left* to *right*): Dr. C. J. Breitwieser, Professor W. G. Cady, Dr. A. M. Zarem, R. L. Sink, Dr. R. M. Ashby, and Dr. W. H. Pickering. Professor Cady, who is a former President of the IRE, has been a Fellow since 1927.

IRE Dictionary Now Available

During the past 18 years, the Institute of Radio Engineers, through its Technical Committees and its Standards Committee, has produced 37 IRE Standards dealing with electronics terminology and symbology. All the definitions and symbols contained in those standards have now been brought together in a single volume entitled "IRE Dictionary of Electronics Terms and Symbols."

The first part of the IRE Dictionary provides an alphabetical list of approximately 3700 technical terms and their IRE Standard definitions. The second part comprises over 50 pages of graphical symbols for diagrams and letter symbols for electron tubes and semiconductor devices.

The "IRE Dictionary of Electronics Terms and Symbols" is now available from the Institute of Radio Engineers, 1 East 79 St., New York 21, N. Y., at the following prices: IRE members, $5.20 per copy; nonmembers, $10.40 per copy.

HIGH-POWER LOW-FREQUENCY DUPLEXERS

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These duplexers are available in both waveguide and coaxial line configurations. Peak power ratings: 1 Mw to 25 Mw. Frequency range: 450 to 9600 Mc. Life expectancy: greater than 2000 hours.

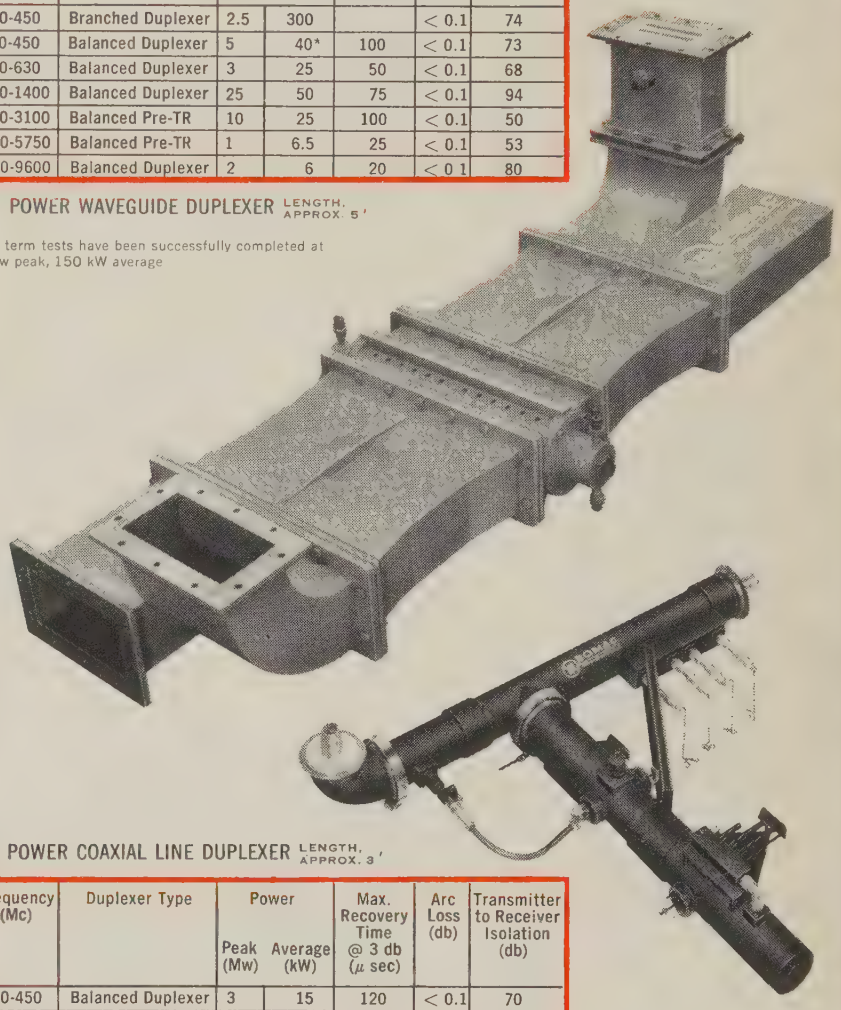
Improved window design provides increased radar capability. Arc loss: much less than 0.1 db. Recovery time at high power is the fastest of any gas switching duplexer on the market. With increased power, recovery time increase is negligible.

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Frequency (Mc)	Duplexer Type	Power		Max. Recovery Time @ 3 db (μ sec)	Arc Loss (db)	Transmitter to Receiver Isolation (db)
		Peak (Mw)	Average (kW)			
400-450	Branched Duplexer	2.5	300		< 0.1	74
400-450	Balanced Duplexer	5	40*	100	< 0.1	73
570-630	Balanced Duplexer	3	25	50	< 0.1	68
1250-1400	Balanced Duplexer	25	50	75	< 0.1	94
2700-3100	Balanced Pre-TR	10	25	100	< 0.1	50
5250-5750	Balanced Pre-TR	1	6.5	25	< 0.1	53
8400-9600	Balanced Duplexer	2	6	20	< 0.1	80

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*Short term tests have been successfully completed at 95 Mw peak, 150 kW average



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Frequency (Mc)	Duplexer Type	Power		Max. Recovery Time @ 3 db (μ sec)	Arc Loss (db)	Transmitter to Receiver Isolation (db)
		Peak (Mw)	Average (kW)			
400-450	Balanced Duplexer	3	15	120	< 0.1	70
400-450	Branched Duplexer	3	5	100	< 0.1	60
850-950	Balanced Duplexer	2	15	100	< 0.1	70

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British IRE Convention on Radio and Space

The 1961 Convention of the British Institution of Radio Engineers will be held at the University of Oxford on July 5–8. The theme of the Convention will be "Radio Techniques and Space Research."

The Convention is concerned with the use of satellites for communications, with research projects such as those to be carried out in the British satellite scheduled for launching by the American "Scout" Rocket towards the end of 1961, and with radio astronomy and satellite tracking. Listed below are the program session titles:

Radio Techniques in Space Research
Satellite Engineering
Extraterrestrial Measurements
Techniques in Radio Astronomy
Satellite Communications

The Institution expects an international delegation of about 500. Approximately 50 papers will be presented, with emphasis on British and Commonwealth achievements and proposals, and also including European papers and specially invited contributions from the U. S. and the U.S.S.R.

During the Convention the Institution's Clerk Maxwell Memorial Lecture will be delivered by a leading space research scientist. The Lecture was founded in 1951 to commemorate the work of James Clerk Maxwell, the eminent 19th century physicist who developed the electromagnetic theory on which modern radio engineering depends.

The Proceedings of the Convention will be published in successive issues of the Institution's *Journal*, beginning in July.

OBITUARY

Philip S. Carter (A'29–M'38–SM'43–F'49) died at his home in Port Jefferson on April 20, 1961, after an extended illness. He was born in Glastonbury, Conn., on July 22, 1897. He graduated from Stanford University, Stanford, Calif., in 1918 with the A.B. degree in mechanical engineering. After serving as Lieutenant in the Signal Corps in World War I, he was employed by the General Electric Company in the laboratory of the famous inventor, Dr. E. F. W. Alexanderson. In the fall of 1919, he was sent to Long Island, N. Y., to investigate directive reception of wireless signals from overseas using insulated wires several miles long laid on the ground near Westhampton. In collaboration with Dr. H. H. Beverage, Chester Rice and B. W. Kellogg, these investigations led to the invention of the wave antenna, which was used extensively for transoceanic reception of radio signals.



P. S. Carter

In 1920, he was transferred to the Radio Corporation of America where he assisted in establishing the RCA Receiving Station at Riverhead, L. I., N. Y., in 1921. The wave antenna was first used at Riverhead and was instrumental in greatly reducing the effects of interference from thunderstorms, which had much to do with the early success of the RCA in establishing a worldwide system of radio communication.

When the short waves came into use in 1925, he became associated with Dr. C. W. Hansell and helped establish the Transmission Research Laboratory at Rocky Point, L. I. He pioneered with Dr. Hansell and N. E. Lindenblad in the invention of directive antennas using long wires. This type of antenna is used all over the world today. For this development and other inventions, he held 100 patents.

Mr. Carter was a brilliant mathematician and had an international reputation as an antenna expert. He published many technical papers in the Proceedings of the IRE which laid the foundation for the theory of directive antennas. He was active on many committees of the IRE; he was a former Chairman of the Antennas Committee and a past Chairman of the Professional Group on Antennas and Propagation.

Phil Carter, as he was universally known, will be sorely missed by his many friends, especially by his associates in RCA Laboratories.

Professional Groups*

Aerospace & Navigational Electronics (G-11)—G. M. Kirkpatrick, Electronics Equipment and Systems Lab., GE Co., Syracuse, N. Y.; H. R. Mimno, Cruft Lab., Harvard Univ., Cambridge 38, Mass.

Antennas & Propagation (G-3)—Dr. H. Fine, Applied Propagation Branch, Technical Research Div., FCC, Washington, D. C.; S. A. Bowhill, Pennsylvania State Univ., University Park, Pa.

Audio (G-1)—C. M. Harris, Electronics Res. Labs., Columbia Univ., New York 27, N. Y.; M. Camras, Armour Res. Foundation, Tech. Ctr., Chicago 16, Ill.

Automatic Control (G-23)—J. M. Salzer, Ramo-Wooldridge, 5500 El Segunda, Hawthorne, Calif.; G. S. Axelby, Westinghouse Air Arm Div., Friendship Airport, Baltimore 3, Md.

Bio-Medical Electronics (G-18)—G. N. Webb, Dept. of Medicine, Biophysical Div., Johns Hopkins Hospital, Baltimore 5, Md.; L. B. Lusted, Dept. of Radiology, Univ. of Rochester, Rochester 20, N. Y.

Broadcast & Television Receivers (G-8)—R. R. Thalner, Sylvania Home Electronics, 700 Ellicott St., Batavia, N. Y.; C. W. Sall, RCA, Princeton, N. J.

Broadcasting (G-2)—R. F. Guy, Nat'l. Broadcasting Co., 30 Rockefeller Plaza, New York 20, N. Y.; W. L. Hughes, E. E. Dept., Iowa State College, Ames, Iowa.

Circuit Theory (G-4)—Dr. J. H. Mulligan, Jr., College of Engrg., New York Univ., University Heights, New York 53, N. Y.; M. E. Van Valkenburg, Dept. of E.E., Univ. of Illinois, Urbana, Ill.

Communications Systems (G-19)—R. L. Marks, Rome Air Dev. Ctr., Griffiss AFB, N. Y.; W. B. Jones, Jr., School of E.E., Georgia Inst. Tech., Atlanta 13, Ga.

Component Parts (G-21)—F. E. Wenger, Headquarters ARDC, Andrews AFB, Washington 25, D. C.; G. Shapiro, Engineering Electronics Sec., Div. 1.6, NBS, Connecticut Ave. and Van Ness St., Washington 25, D. C.

Education (G-25)—J. G. Truxal, Head, Dept. of E.E., Polytech. Inst. Brooklyn, 333 Jay St., Brooklyn, N. Y.; W. R. LePage, Dept. of E.E., Syracuse Univ., Syracuse 10, N. Y.

Electron Devices (G-15)—W. A. Adcock, Texas Instruments, 6000 Lemmon Ave., Dallas 9, Tex.; E. L. Steele, Hughes Prods., Inc., 500 Superior Ave., M.S., A 2308, Newport Beach, Calif.

Electronic Computers (G-16)—A. A. Cohen, Remington Rand Univac, St. Paul 16, Minn.; H. E. Tompkins, c/o E. K. Gannett, IRE, 1 East 79 St., New York 21, N. Y.

Engineering Management (G-14)—T. W. Jarmie, Engineered Electronics Co., 1441 E. Chestnut Ave., Santa Ana, Calif.; A. H. Rubenstein, Dept. of Indus. Engrg., Northwestern Univ., Evanston, Ill.

Engineering Writing and Speech (G-16)—J. M. Kinn, Jr., *IBM Journal*, 17th Floor, 545 Madison Ave., New York, N. Y.; H. B. Michaelson, IBM Res. Ctr., Box 218, Yorktown Heights, N. Y.

Human Factors in Electronics (G-28)—R. R. Riesz, Bell Telephone Labs., Murray Hill, N. J.; J. I. Elkind, Bolt Beranek and Newman, Inc., 50 Moulton St., Cambridge, Mass.

Industrial Electronics (G-13)—J. E. Eiselein, RCA Victor Div., Camden, N. J.; R. W. Bull, Coleman Instruments, Inc., 42 Madison St., Maywood, Ill.

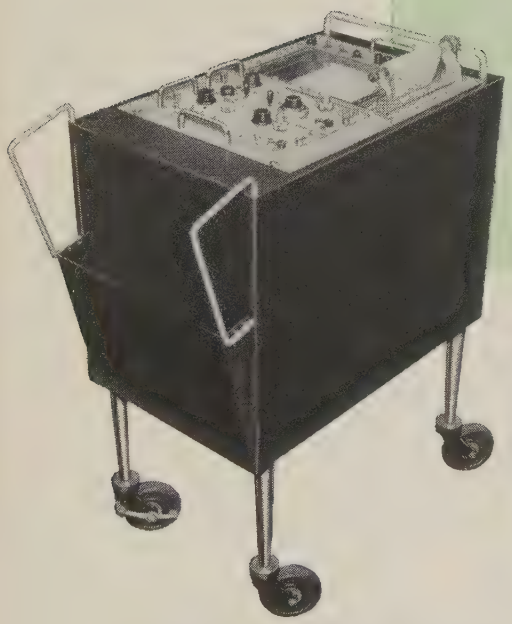
Information Theory (G-12)—P. E. Green, Jr., Lincoln Lab., MIT, Lexington,

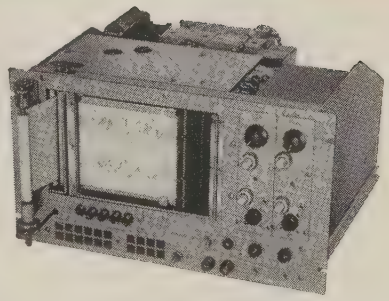
* Names listed are Group Chairmen and Transactions Editors.

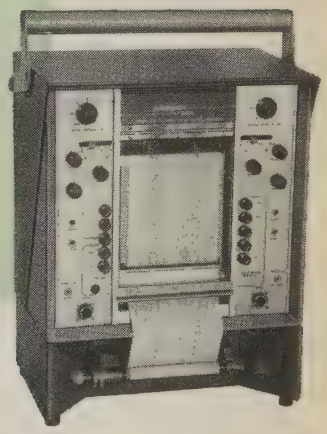


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With simplified, miniaturized preamps: Model 297 sensitivities from uv to hundreds of volts; transistorized electronics; "850" preamps include Phase Sensitive Demodulator, DC Coupling, Carrier, Low Level types, plus MOPA for chopper and carrier excitation; system occupies 10½″ in rack.

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New Model 321 Carrier for AC transducer work: maximum sensitivity 10 uv rms/mm; excitation 5 volts; transducer impedance 100 ohms min; uncalibrated zero suppression.

Model 320 General Purpose DC (illustrated): 12 sensitivities 0.5 to 20 mv/mm and v/cm; input impedance ½ megohm (mv/mm ranges) and 1 megohm (v/cm ranges); floating and guarded inputs.

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Mass.; A. Kohlenberg, Melpar Inc., 11 Galen St., Watertown, Mass.

Instrumentation (G-9)—H. W. Lance, Nat'l. Bureau of Standards, Boulder, Colo.; G. B. Hoadley, Dept. of E.E., North Carolina State College, Raleigh, N. C.

Microwave Theory and Techniques (G-17) T. N. Anderson, EMT Corp., Syosset Industrial Park, 210 Michael Dr., Syosset, L. I., N. Y.; D. D. King, Electronic Comm., Inc., 1830 York Rd., Timonium, Md.

Military Electronics (G-24)—W. L. Doxey, EC Dept., USASRDL, Fort Monmouth, N. J.; D. R. Rhodes, Radiation Inc., Box 6904, Orlando, Fla.

Nuclear Science (G-5)—L. Costrell, Nucleonic Inst. Sec., NBS, Washington 25, D. C.; R. F. Shea, Dig Power Plant Engrg., Knolls Atomic Power Lab., General Electric Co., Schenectady, N. Y.

Product Engineering and Production (G-22)—A. R. Gray, Astronics of Florida, Inc., 1110 S. Woods St., Box 5606, Orlando, Fla.; D. B. Ehrenpreis, 325 Spring St., New York, N. Y.

Radio Frequency Interference (G-27)—H. E. Dinger, Naval Research Lab., Washington 25, D. C.; O. P. Schreiber, Technical Wire Prods., Inc., 48 Brown Ave., Springfield, N. J.

Reliability and Quality Control (G-7)—P. K. McElroy, General Radio Co., 22 Baker Ave., West Concord, Mass.; W. X. Lamb, Jr., 22124 Dumetz Rd., Woodland Hills, Calif.

Space Electronics and Telemetry (G-10)—K. M. Uglow, Jr., 2228 Oriole Dr., Sarasota, Fla.; F. T. Sinnott, Mail Zone 549-30, Convair-Astronautics, San Diego 12, Calif.

Ultrasonics Engineering (G-20)—V. Salmon, Stanford Research Inst., Menlo Park, Calif.; O. E. Mattiat, Res. Div., Acoustica Associates Inc., 415 E. Moutecito St., Santa Barbara, Calif.

Vehicular Communications (G-6)—R. P. Gifford, General Electric Co., Rm. 206, Mountain View Rd., Lynchburg, Va.; W. G. Chaney, AT&T Co., 195 Broadway, New York 7, N. Y.

Sections*

Akron (4)—V. J. Chimera, 2156 Springfield Center Rd., Akron 12, Ohio; C. M. Kelly, 2915 Silver Lake Circle, Cuyahoga Falls, Ohio.

Alamogordo-Hollman (7)—W. S. Stotts, 1507 Michigan Ave., Alamogordo, N. M.; H. T. Castillo, 2611 Pontiac Ave., Alamogordo, N. M.

Albuquerque-Los Alamos (7)—R. Creveling, 1415 Park Ave., S.W., Albuquerque, N. M.; R. P. Noble, 1001 Chama, N.E., Albuquerque, N. M.

Anchorage (7)—T. R. Young, 415 11th Ave., Anchorage, Alaska; C. A. Johnson, 1536 "I" St., Anchorage, Alaska.

Atlanta (3)—H. C. Craddock, Jr., 1059 Lindridge Dr., N.E., Atlanta 5, Ga.; R. L. Ellis, Jr., 77 Karland Dr., N.W., Atlanta, Ga.

Baltimore (3)—J. A. Houston, 1825 Dunwoody Rd., Baltimore 34, Md.; W. C. Gore, 1400 Glendale Rd., Baltimore 12, Md.

Bay of Quinte (8)—R. Williamson, 74 Selena Ave., Belleville, Ont., Canada; D. J. Cowan, 3 Smith Crescent, Belleville, Ont., Canada.

Beaumont-Port Arthur (6)—H. W. Bartlett, 3790 Ironton, Beaumont, Tex.; R. Cunningham, Rte. 1, Box 181, Kirbyville, Tex.

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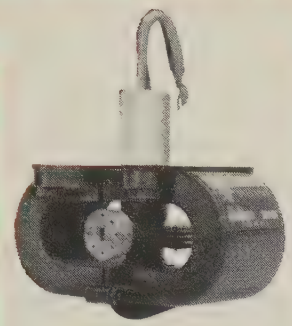
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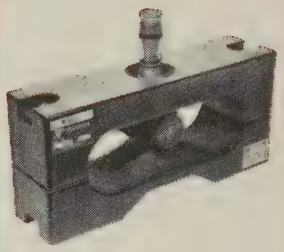
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6799	34.512 35.208	120	.0005	1.0
M-4155A	34.512 35.208	40	.0006	1.0
XM-4064	34.512 35.208	70	.0008	1.0
XM-4158	34.512 35.208	120	.0008	1.0
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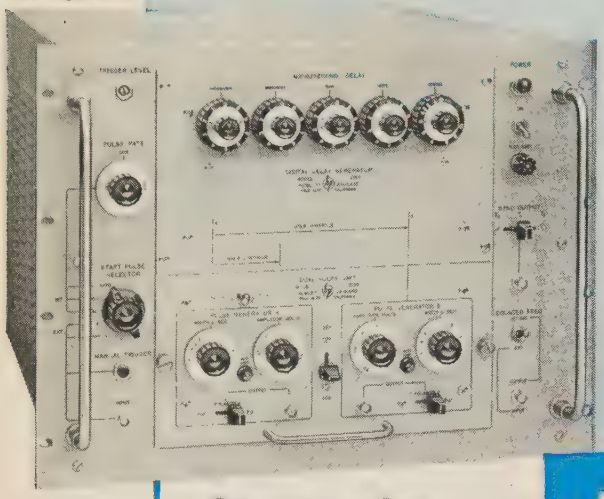
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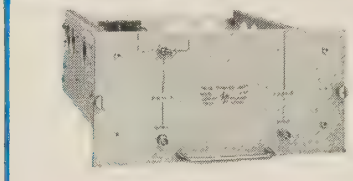
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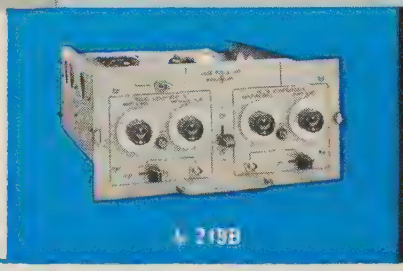
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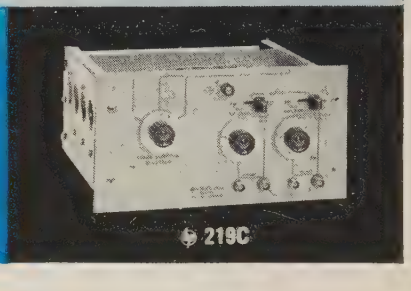
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219A



219B



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Lehigh Valley (3)—J. H. Volk, 411 Grant St., Easton, Pa.; A. I. Larky, Lehigh Univ., Dept. of Elec. Engrg., Bethlehem, Pa.

Memphis (3)—C. Ray, Dept. of Neurosurgery, Baptist Memorial Hospital, Memphis 3, Tenn.; Brother I. J. Haas, Christian Brothers College, Memphis 4, Tenn.

Merrimac Valley (1)—D. D. Sagaser, Bell Telephone Labs., 1600 Osgood St., North Andover, Mass.; W. Banton, 21 Walnut St., North Andover, Mass.

Mid-Hudson (2)—R. J. Domenico, IBM Research Lab., Poughkeepsie, N. Y.; W. Cadden, 67 Round Hill Rd., Poughkeepsie, N. Y.

Monmouth (2)—J. A. Young, Jr., 40 Buttonwood Dr., Fairhaven, N. J.; O. E. DeLange, Bell Telephone Labs., Holmdel, N. J.

Nashville (3)—G. P. McAllister, 2923 Twin Lawn Dr., Nashville 14, Tenn.; W. B. Kincaid, Jr., 210 Graeme Dr., Nashville 14, Tenn.

New Hampshire (1)—R. Baer, 134 Mayflower Dr., Manchester, N. H.; F. J. Safford, 71 Concord St., Nashua, N. H.

Northern Vermont (1)—F. J. M. Sichel, 35 Henderson Terrace, Burlington, Vt.; W. C. Chase, WDEV, 9 Stowe St., Waterbury, Vt.

Orange Belt (7)—J. F. McElwee, 455 N. Live Oak Ave., Glendora, Calif.; A. G. Holtum, Jr., 941 E. Marylind, Claremont, Calif.

Palm Beach (3)—C. E. Cronin, 544 Ebb Tide Dr., North Palm Beach, Fla.; A. S. Baran, 301 Bayside Rd., Lake Worth, Fla.

Panama City (3)—J. F. Ault, 1305 Cornell Dr., Panama City, Fla.; R. C. Lowry, 2342 Pretty Bayou Dr., Panama City, Fla.

Pasadena (7)—J. W. Thatcher, 936 Winston Ave., San Marino, Calif.; R. L. Heacock, 2532 Hanning Ave., Altadena, Calif.

Pikes Peak (6)—A. O. Behnke, 204 Westcott Ave., Colorado Springs, Colo.; secretary to be advised.

Reading (3)—W. I. Huyett, 1020 Wyomissing Blvd., Wyomissing, Pa.; R. H. Lundberg, 3312 Harrison Ave., Reading, Pa.

Richland (7)—P. R. Kelly, 220 Delafield, Richland, Wash.; G. L. Erickson, 213 Armistead, Richland, Wash.

San Fernando Valley (7)—J. D. Wills, 6606 Lindley, Reseda, Calif.; C. Z. Becker, RCA, 8500 Balboa Ave., Van Nuys, Calif.

Santa Ana (7)—D. R. Proctor, 1601 East Chestnut Ave., Santa Ana, Calif.; J. C. Hathaway, Collins Radio Co., 3324 West Delhi Road, Santa Ana, Calif.

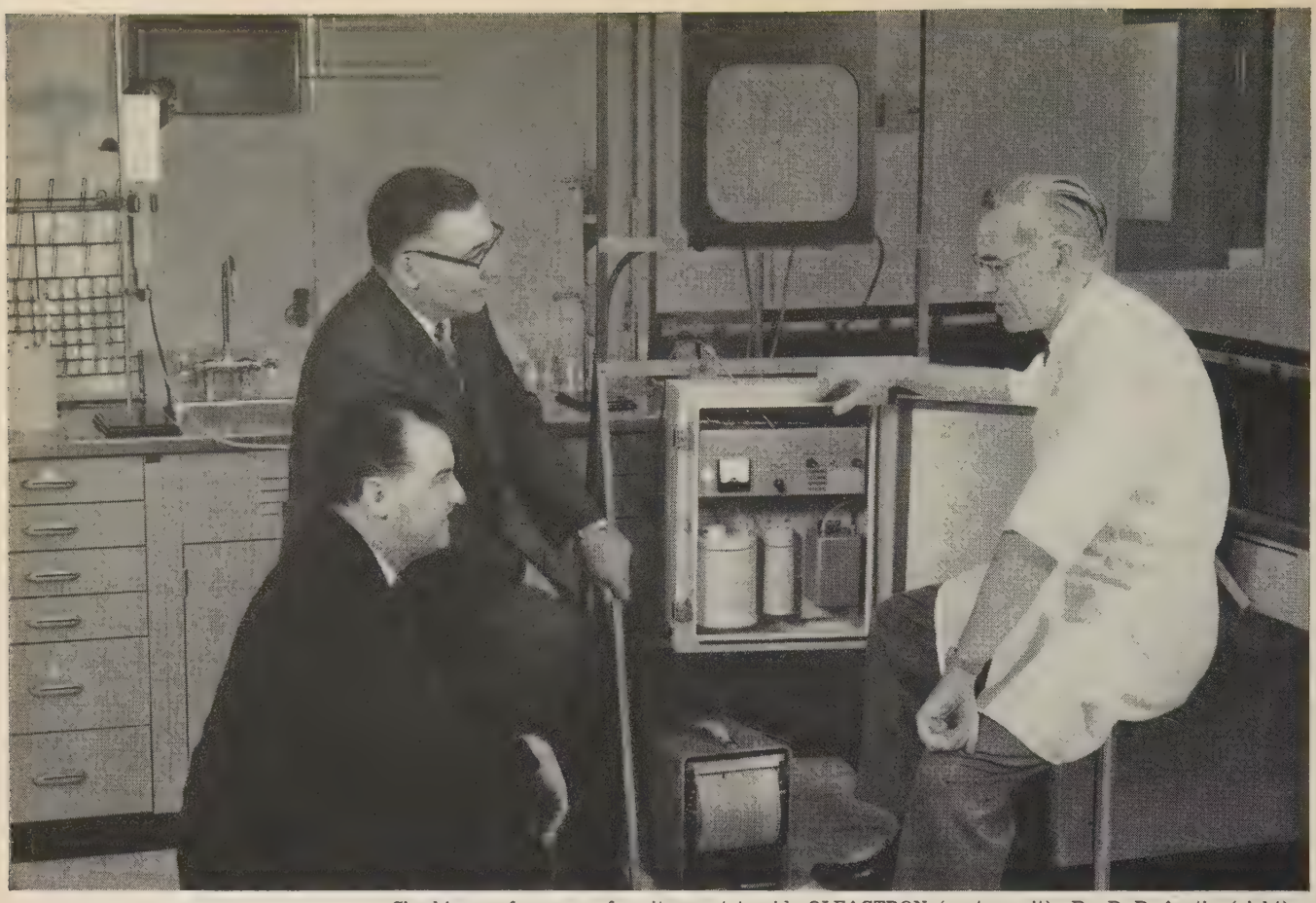
Santa Barbara (7)—Chairman to be advised; R. S. Hutcheon, 714 Chiquita Rd., Santa Barbara, Calif.

Southwestern Ontario (8)—W. A. Ruse, Bell Telephone Co., 1149 Goyeau St., Windsor, Ont., Canada; G. L. Virtue, 619 Lounsborough Rd., Sandwich - South, Windsor, Ont., Canada.

Victoria (8)—Officers to be advised.

Westchester County (2)—M. Ziserman, 121 Westmoreland Ave., White Plains, N. Y.; M. L. Brailey, 12 Dupont Ave., White Plains, N. Y.

Western North Carolina (3)—J. I. Barron, Southern Bell T&T Co., Box 240, Charlotte, N. C.; T. C. Livingston, 926 N. Sharon Amity Rd., Charlotte, N. C.



Checking performance of a nitrogen tetroxide OLFACTRON (center unit): Dr. R. R. Austin (right), with Mr. D. S. Barlow, Vice President (left), and Mr. L. M. Ballard (center) of the Instrument Division.

A Report from American Systems Incorporated...

Exotic Propellant Vapor Detection

As a major step in its program of developments for the aerospace field, American Systems Incorporated is introducing a new type of instrument for detection of toxic propellant vapors. Called OLFACTRONS because they act like an electrochemical "nose," quantitatively measuring vapors in amounts too slight to be detected by human senses, these instruments increase safety and effectiveness in handling high-energy propellants.

In the OLFACTRON principle, the vapor sensed produces a proportional electric current, which in turn is indicated on a meter, or recorded. The instruments are fast-acting, and can be integrated easily into electronic warning systems. OLFACTRONS are now available for detection of hydrazine, UDMH, nitrogen tetroxide, and borane. Similar instruments for detection of sulfur, hydrocarbons, and moisture are in production for the natural gas, LP gas, petrochemical, and chemical industries.

Developed by Dr. Robert R. Austin and Myron L. Robinson, in association with the Instrument Division of American Systems, OLFACTRONS illustrate the systems influence in practical instrumentation design. The instruments are adaptable to system networks involving communications, computation, and data processing.

Complementing the work of the Instrument Division, technical programs are under way in six other Divisions:

INFORMATION SCIENCES

Mathematical and statistical research; computer programming, and advanced programming systems; computation services; digital system studies; logical design; advanced systems analysis.

DATA PROCESSING

Data processing subsystems research and development; logic of command and control complexes; optical recognition systems.

ELECTROMAGNETIC SYSTEMS

Electromagnetic physics; electronic and mechanical scanning antenna systems; development and manufacturing of complete sensor systems and special microwave components.

RESEARCH LABORATORIES

Solid state physics and systems; magnetic thin-film research and subsystems; advanced components for information processing.

COMPONENT DEVELOPMENT

Advanced component technology; materials and processes; computer component development; chemical deposition of magnetic surfaces on drums, disks, rods.

AUDIO-VISUAL

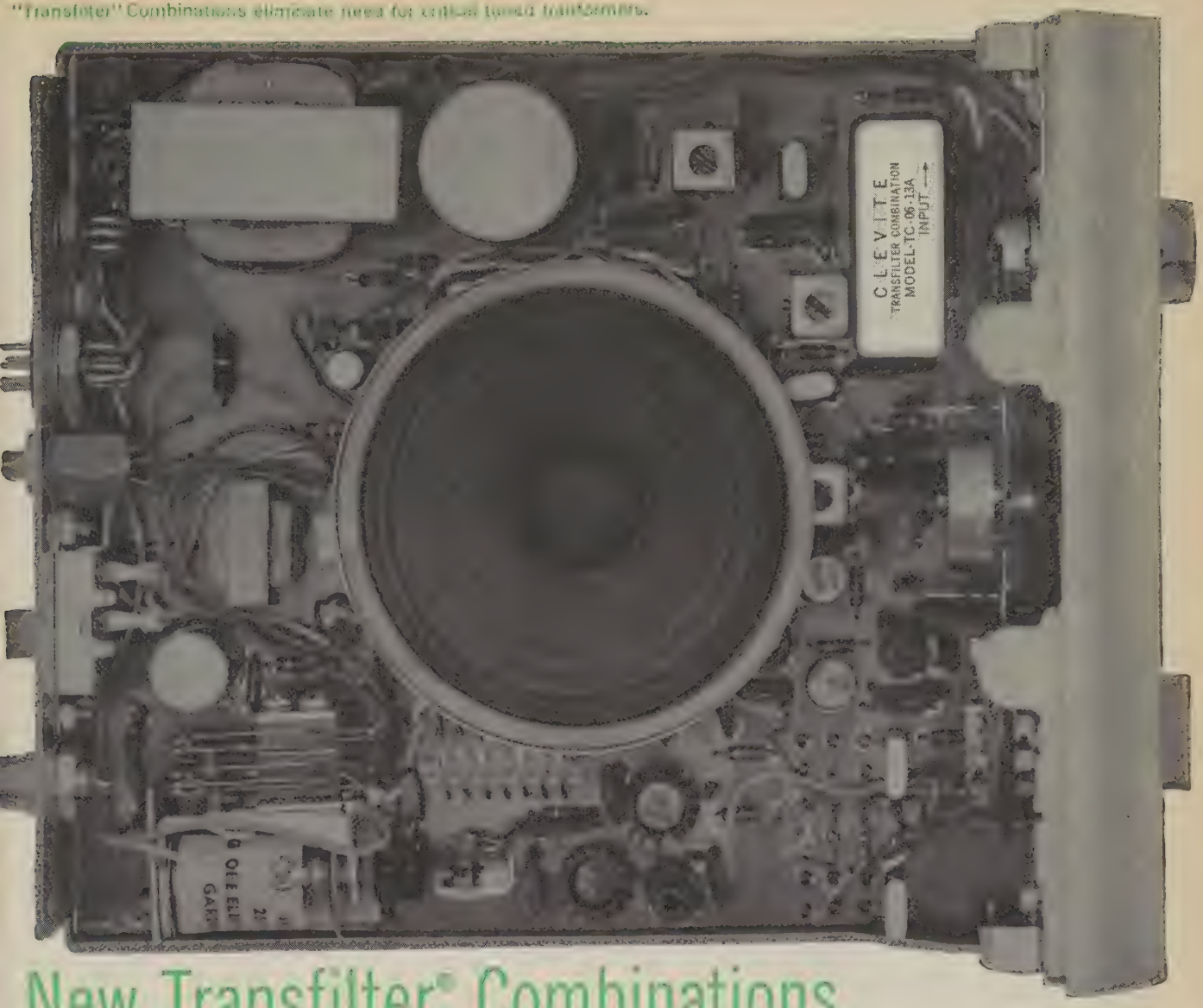
Audio-visual (INSTRUCTRON) devices for assembly line and instructional applications; production of work stations designed on human factors principles.

Qualified scientists and engineers who are interested and experienced in these fields of activity are encouraged to investigate career opportunities with American Systems.

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AMERICAN SYSTEMS *Incorporated*
1625 East 126th Street, Hawthorne, California
AN AFFILIATE OF SCHLUMBERGER

Compact chassis of Gatsome 300 CBT Citizens Band Transceiver "Transfilter" Combinations eliminate need for critical tuned transformers.



New Transfilter® Combinations

Greater selectivity in a miniature package

. . . and increased stability at a decreased cost. Further, magnetic shielding can be eliminated as well as the necessity for factory and field alignment. That's why CLEVITE'S ceramic i-f filters are rapidly replacing conventional components in today's mobile or high quality commercial receivers. Basic component of these rugged fixed-tuned devices is the CLEVITE piezoelectric "Transfilter" developed especially for great stability of resonant frequency with respect to time and temperature. Cascading and coupling these resonators provide excellent selectivity at desired bandwidths. Size, 1½" x ¾" x 2.0" high; Center Frequency, 455 kc; Shape Factor (60/6db), 3:1 to 5:1; Bandwidth, 4 to 20 kc; Insertion Loss, 6 to 12 db max. (depending on bandwidth); Impedance, 2700 ohms in and out; Temperature Range, –20°C to +90°C. Call, write or wire for complete details.



CLEVITE ELECTRONIC COMPONENTS
232 Forbes Road, Bedford, Ohio / Division of CLEVITE Corporation



accurate amplification of low-level signals from DC to beyond 200 kc?



The KIN TEL 121A/A is a non-inverting amplifier with response from DC to beyond 200 kc. It has fixed gains of 0, +1, +10, +20, +30, +50, +100, +200, +300, +500, and +1000, and a control that adjusts any fixed gain from X1 to X2.2. Amplification is stable within 0.01%, accurate within 0.1% for all gains other than +1 (0.2% accuracy at +1), linear within 0.005% for outputs up to ±15 volts DC with loads of 200 ohms or more. Input impedance is greater than 10 megohms (less than 500 pf to 50 kc); output impedance is less than 0.3 ohm and 50 μh. Frequency response is flat within 0.25% to 2 kc, within 4% to 10 kc, within 3 db to 200 kc. Drift is less than ±2.0 μv equivalent input for over 40 hours at +1000 gain. Equivalent input noise at +1000 gain is 3 μv peak-to-peak in a 20-cps band, 3 μv RMS in a 50-kc band. Output capability is ±15 volts into 200 ohms, ±100 ma into 10 to 100 ohms. Amplifier fits standard KIN TEL cabinets and modules. Price $1000.

Representatives in all major cities

KIN TEL
A DIVISION OF
COHU
ELECTRONICS, INC.

5725 Kearny Villa Road, San Diego 11, California
Phone: BRowning 7-6700

Industrial Engineering Notes

Governmental and Legislative

The FCC has authorized the Westinghouse Broadcasting Company, Inc. to operate an experimenta radio station to bounce signals off of the moon and passive earth satellites for basic research work and study of space communications The earth station will be located near Linthicum, Md., and reflected signals will be received by the same station. The authorization, which extends to November 1, specifies operation on the center frequency of 550 Mc, with power of 2000 watts maximum into the antenna. Since the authorized frequency was not in a band allocated for space research in the Geneva 1959 Radio Regulations, operational use is not permitted, the FCC said. The authorization is subject to conditions including "without prejudice to such action as the Commission may deem warranted as a result of its pending inquiry into antitrust matters.". . **The use of portable FM radios on United States civil aircraft has been prohibited by the Federal Aviation Agency in a Special Civil Air Regulation issued recently and effective May 25, 1961.** FAA said the rule was based on results of an investigation of the effect of portable electronic devices operated in aircraft, including radios, dictating machines and recorders. Only radios having oscillators operating within or very near the very high frequency band used in aircraft, 108 to 118 megacycles, affected instruments in the various aircraft on which the tests were made, the Agency said More detailed tests will be made later in the year. The interference discovered by the FAA affected the VHF radio navigation system of the aircraft, causing the appearance of the "red flag," indicating to the pilot that the navigation instrument was not working properly, FAA reported. The red flag warns the pilot not to trust the instrument, and thus prevents the instrument from giving faulty indications. In most cases of interference the flag alarm system worked satisfactorily. However, to preclude the chance that the interference might go undetected, the FAA established a rule to guide carriers and commercial operators. Pilots of other aircraft shall not permit use of such radio receivers when VOR navigating equipment is in use on their planes. The new rule, Special Civil Air Regulation SR 446, will remain in effect for one year unless superseded or rescinded by the FAA

Industry Marketing Data

Factory sales of transistors showed a healthy gain in March of 1,858,845 units worth $4,115,666 over February totals, Marketing Data Department figures have disclosed. Transistors sold at the factory in March totaled 15,129,273 valued at $29,815,291. In February, the totals were 13,270,428 units sold and $25,699,625 in revenue from sales. For the first three months of this year, 40,583,632 transistors worth $78,470,083 were sold at the factory compared with 31,155,798 units worth $78,246,279 sold during the same period in 1960.

Military and Space

Radio Corporation of America has been selected for contract negotiations to construct the Relay experimental communication satellite to test the feasibility of transoceanic telephone, telegraph, and television communications using an active repeater satellite, the National Aeronautics and Space Administration disclosed recently. The Goddard Space Flight Center, NASA's installation having responsibility for communication satellite programs, will negotiate and manage the contract, which will amount to approximately $3,250,000. The RCA proposal was selected from seven proposals submitted to the Goddard Center, NASA said. Relay is the first active satellite in NASA's research and development program to explore the technology of global communication satellite systems. It differs from Project Echo and follow-on developments in the passive satellite field in that the spacecraft will contain electronic equipment to receive and retransmit radio signals between the United States and overseas points. The Relay satellite will weigh about one hundred pounds, and will be placed in an orbit extending outward to about 3000 miles. A Delta launch vehicle will be used. The spacecraft will contain instruments to detect radiation damage and other environmental effects on critical components as well as the communications equipment. It will be launched from Cape Canaveral.

* The data on which these NOTES are based were selected by permission from *Weekly Report* issues of May 15 and 22, 1961, published by the Electronic Industries Association, whose helpfulness is gratefully acknowledged.

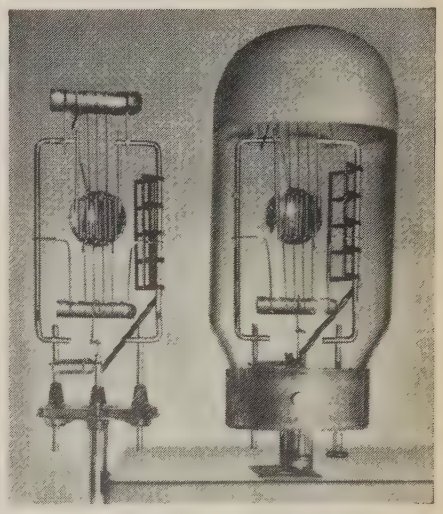
Don't miss the WESCON Show
Aug. 22-25, 1961
Cow Palace and Fairmont Hotel
San Francisco, Calif.

Vol. 2, No. 1 **Nickelectric News** DEVELOPMENTS IN INCO NICKEL AND NICKEL ALLOYS AND THEIR APPLICATIONS

How Huntington Alloys handle 5 rugged electronic assignments

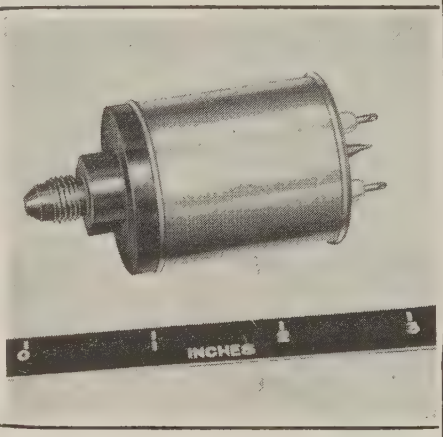


Packaging a small relay for big voltage. Jennings high vacuum transfer relays are built for great dielectric strength—the type RE6B shown will actually withstand 84,000 volts internally, with a contact gap of only 0.030 inches. For low, stable contact resistance, better degassing for contamination-free contact, Monel* nickel-copper "403" alloy was used in exterior and interior housing. The "403" alloy closely matches the expansion coefficient of Armco magnetic iron in the magnet coil circuit so parts retain close fit after brazing. It forms the inner housing seal to isolate actuating coil from the vacuum, and—being nonmagnetic—does not "short" or distort the magnetic path.

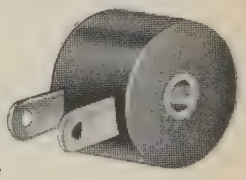


"A" Nickel grid damps out convection currents. In the new Westinghouse projection lamps the screen collector grid must be kept free of even small amounts of water vapor—otherwise, filament and lamps would quickly deteriorate. "A" Nickel was Electronic Grade selected to form the grid because it is easily outgassed without deformation. Since no trace of water vapor remains after outgassing, there is no attack on the tungsten filament.

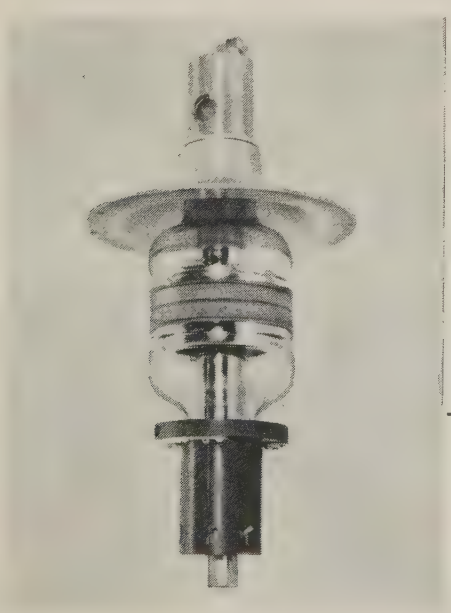
How to make a pressure switch for hot spots. Consolidated Controls Corporation of Bethel, Conn., had to build its Type 212C07 High Temperature Absolute Pressure Switch for service ranging from −65° to 1000°F. Its prime job is in hot spots near engines in missiles and rockets. Inconel "X"* age-hardenable nickel-chromium alloy was selected for the diaphragm, housings and switch assembly because of its high tensile and yield strength at 1000°F, and its resistance to chemical corrosion and oxidation.



Case of the high-flying resistor.



Secure mounting reinforcement for resistors with tolerances of 0.01% was the job Ultronix, Inc., had to tackle for circuits in missiles and computers. They found the answer with Monel nickel-copper alloy tubing produced by Superior Tube Co. Its thermal expansion coefficient is compatible with resistance wire and plastic which encapsulates the resistor. The Monel tubing maintains its high resistance to oxidation and corrosion from −60° to 300°F. *Inco trademarks



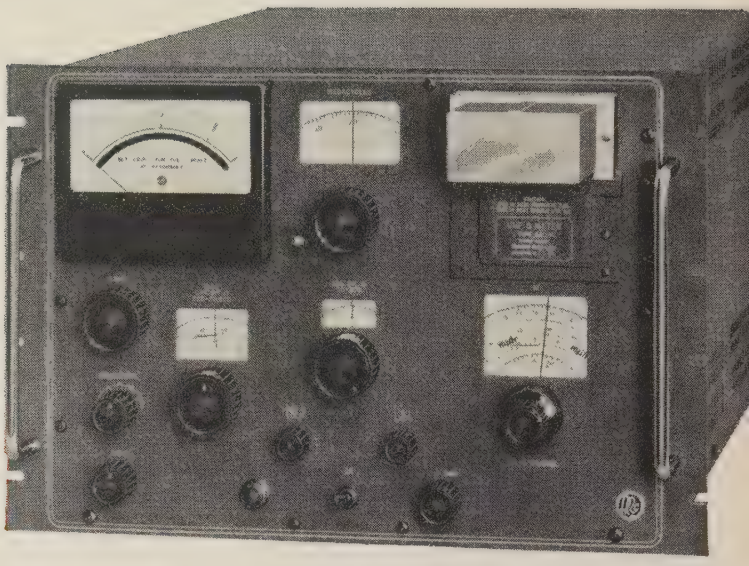
Avoiding "sputter" in X-ray tubes. Low-carbon, ferrous-alloy electrodes in high voltage X-ray tubes meant fast corrosion of parts before they were under vacuum, and sputtering of the metal under high voltage outgassing. The Machlett Laboratories chose Low Carbon Nickel for electrodes in their EG-252 X-ray tube to avoid these problems. Moreover, they found it could be easily spun into intricate shapes. Low Carbon Nickel also permitted safe outgassing at temperatures to 800°C. for long tube life.

INCO TRADE MARK

HUNTINGTON ALLOY PRODUCTS DIVISION
The International Nickel Company, Inc.
Huntington 17, West Virginia

HUNTINGTON ALLOYS

New!
TYPE
280-A



UHF Q METER 210

—measures COMPONENTS, CAVITIES, SEMI-CONDUCTORS

Description

The new UHF Q Meter Type 280-A is a unique self-contain instrument for measuring the RF characteristics of componer in the UHF range. The instrument consists of a specially design oscillator, Q measuring circuit, and resonance indicator and, application, is similar to its counterparts in the lower frequen ranges. In addition to performing conventional Q Meter measu ments, in which the unknown component is resonated with t internal calibrated capacitor, the output of the oscillator and t input of the resonance indicator are available externally for rectly measuring the Q of self-resonant devices.

The UHF Q Meter differs from conventional Q Meters in that measures the actual percentage bandwidth of the resonance cur and, from this data, computes and reads out circuit Q. The te circuit is first tuned to resonance by adjusting oscillator frequen and/or resonating capacitance. The circuit is then detuned fr the half-power point on one side of the resonance curve to t opposite half-power point by adjusting a calibrated dial, coupled the oscillator frequency control, which directly reads out circuit

Precision Electronic Instruments since 1934

BOONTON RADIO

BOONTON, NEW JERSEY • Tel. DEERFIELD 4-320

- 10-25,000 TOTAL Q RANGE
- SELF-CORRECTING UHF RESONATING CAPACITOR
- DIRECT-READING INDUCTANCE SCALE
- 25 MV RF MEASURING LEVEL
- MEASURES "IN-CIRCUIT" Q OF SELF-RESONANT CIRCUITS

610 MC

by

Specifications

Radio Frequency Characteristics

RF RANGE: 210 to 610 MC

RF ACCURACY: ±3%

RF CALIBRATION: Increments of approximately 1%

RF MONITOR OUTPUT: 10 mv. minimum into 50 ohms*
*at frequency monitoring jack

Q Measurement Characteristics

Q RANGE:
Total Range: 10 to 25,000*
High Range: 200 to 25,000*
Low Range: 10 to 200
*10 to approx. 2,000 employing internal resonating capacitor

Q ACCURACY: ±20% of indicated Q

Q CALIBRATION:
High Q Scale: Increments of 1—5% up to 2,000
Low Q Scale: Increments of 3—5%

Inductance Measurement Characteristics

L RANGE: 2.5 to 146 mμh*
*actual range depends upon measuring frequency

L ACCURACY: ±11 to 15%*
*accuracy depends upon resonating capacitance

L CALIBRATION: Increments of approx. 5%

Resonating Capacitor Characteristics

CAPACITOR RANGE: 4 to 25 μμf

CAPACITOR ACCURACY: ± (5% + 0.2 μμf)

CAPACITOR CALIBRATION:
0.05 μμf increments, 4-5 μμf
0.1 μμf increments, 5-15 μμf
0.2 μμf increments, 15-25 μμf

Measurement Voltage Level

RF LEVELS: 25, 40, 80, 140, 250 mv. nominal*
*across measuring terminals

Physical Characteristics

MOUNTING: Cabinet for bench use; by removal of end covers, suitable for 19" rack mounting.

FINISH: Gray wrinkle, engraved panel (other finishes available on special order).

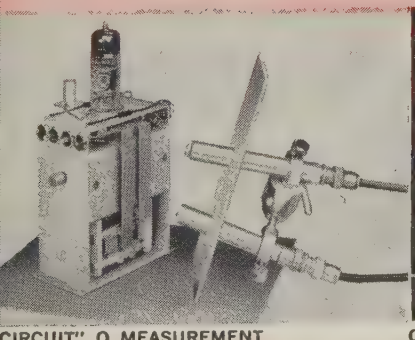
DIMENSIONS: Height: 12-7/32" Width: 19" Depth: 17"

WEIGHT: Net: 72 lbs.

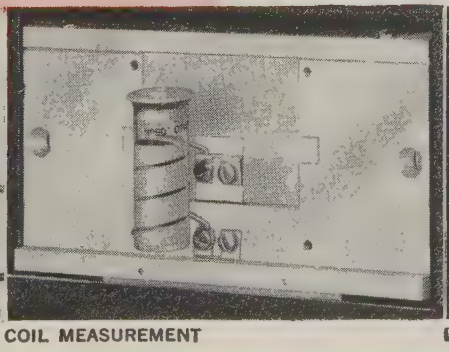
Power Requirements

280-A : 105-125/210-250 volts, 60 cps, 140 watts
280-AP: 105-125/210-250 volts, 50 cps, 140 watts

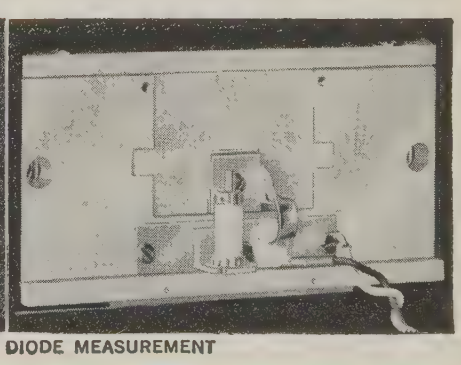
Price: 280-A: $2,375.00 280-AP: $2,375.00
F.O.B. Boonton, N. J.



CIRCUIT" Q MEASUREMENT



COIL MEASUREMENT



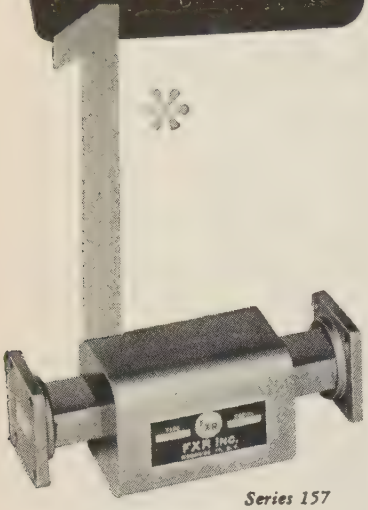
DIODE MEASUREMENT

CORPORATION

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FXR's
FERRITE ISOLATORS



Series 157

OPERATION: Full waveguide bandwidth
RANGE: Waveguide 3.95 to 26.50 KMc Coax 2.0 to 4.0 KMc
ISOLATION: 15 to 30 db depending upon range
VSWR: Waveguide 1.15 max Coax 1.2 max
INSERTION LOSS: 1db max

No. 1 of a series of FXR's new precision microwave components designed to meet the ever-growing needs of the microwave industry.

FXR's Ferrite Isolators are broadband, high performance waveguide and coaxial microwave components which provide maximum isolation and minimum insertion loss. In general these isolators are used in any application where it is desired to attenuate either the forward or reverse power flow without corresponding attenuation in the opposite direction. They are used to reduce the VSWR presented by a load and to isolate the oscillator for more stable operation.

Model No.	Frequency Range KMc	Minimum Isolation db	Peak Power	Price
H157A	3.95- 5.85	18	*2KW	$240.00
C157A	5.85- 8.20	20	*2KW	220.00
W157A	7.05-10	24	*2KW	220.00
X157A	8.20-12.4	30	*2KW	195.00
Y157A	12.40-18	24	**1KW	220.00
K157A	18.00-26.50	24	**1KW	240.00
K157AF†				240.00
N157A	2.00- 4.00	15	**2KW	390.00

*Load VSWR 5 **Load VSWR 2
†K157AF has the same specifications as K157A, except for the flange.

Write for Catalog Sheet No. 157

FXR a division of
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Woodside, N. Y. / TWX: NY 43745

IRE People

Henry C. Alberts (M'59) has been appointed Director of Marketing of the Northeastern United States for the National Company, Inc., of Malden, Mass.



H. C. Alberts

Previously, he was employed as New England Sales Representative for Cook Electric Company. From 1956–1959 he served as Technical Coordinator and Head of the Systems Analysis Group of Avco Corporation's Research and Advanced Development Division.

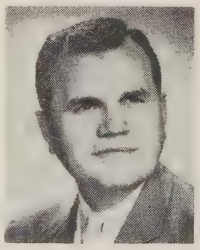
From 1953–1956 he served as physicist with the Requirements Section, Geophysics Research Directorate at the Air Force's Cambridge Research Center. Before that, he had worked as an Army physicist at the Ballistic Research Laboratory of the Aberdeen Proving Ground.

A graduate of Queens College, Flushing, N. Y., he received the M.S. degree from the University of Delaware, Newark, and is a former consultant and guest lecturer on operations research and systems analysis at Pennsylvania State University, University Park.

Mr. Alberts is a member of the American Institute of Physics, the American Physical Society, and the American Rocket Society.

❖

Tore N. Anderson (S'47-A'49-SM'55) was elected President and Chairman of the Board of E.M.T. Corporation, Syosset, L. I., N. Y. at a meeting of the Board of Directors which was held on May 1, 1961.



T. N. Anderson

E.M.T. Corporation, which specializes in Flexible Waveguides for the Microwave Industry, has been at its new plant in the Syosset Industrial Park since January, 1961, after having acquired Marflex, Inc., a precision machine and tool shop, to facilitate production.

Mr. Anderson, former President of FXR, Inc., was Vice President and Director of Engineering at Airtron, Inc., Division of Litton Industries, for nearly twelve years.

He is Chairman of the IRE Professional Group on Microwave Theory and Techniques and a Consultant to the Department of Defense Advisory Group on Electron Parts.

He has been active in Waveguide Standardization with the EIA and is the U. S. Delegate to the International Electrotechnical Commission, and Secretary of the IEC Committee SC46A on International Waveguide Standards.

He holds a number of patents in the microwave ferrite devices. He is an associate editor of the "Microwave Journal," a member of the American Physical Society, and the AIEE.

❖

Dr. Stephen J. Angello (S'52–F'59,) Project Manager in the New Products Laboratories of Westinghouse Electric Corporation, has been named visiting Mackay Professor of Electrical Engineering at the University of California at Berkeley. He will present a special series of lectures in the field of semiconductors at the University's department of electrical engineering.

The lecture series will deal with molecular electronics, thermoelectricity and silicon rectifiers—areas of semiconductor research with which he has been closely identified. He has been Project Manager directing the Westinghouse technical effort in both molecular electronics and thermoelectricity. He headed the work in silicon rectifier development which led to the establishment of the Westinghouse Semiconductor Department.

A native of Haddonfield, N. J., he received his undergraduate and graduate training at the University of Pennsylvania, University Park. He came to Westinghouse in 1942 as a research engineer. He has served as Manager of Semiconductor Development in the Westinghouse Materials Laboratories, and as Engineering Manager of the Westinghouse Semiconductor Laboratories, Youngwood, Pa. He is currently Project Manager for the Company's research program in molecular electronics.

Dr. Angello is a member of the American Physical Society and the American Institute of Electrical Engineers.

❖

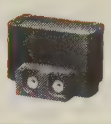
Dr. Nicholas A. Begovich (S'41–A'48–M'58), who was responsible for the development of three-dimensional radar at Hughes Aircraft Company, has been appointed a Vice President, it was recently announced.

Dr Begovich, who is Assistant Manager of the company's ground systems group in Fullerton, Calif., and Director of product line operations there, conceived the idea of radar scanning by electronic means rather than mechanical. He later in-

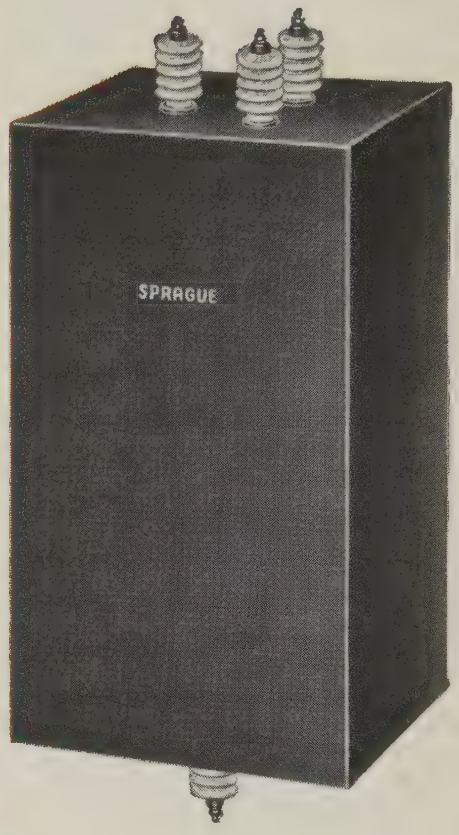
(Continued on page 36A)

PULSE-FORMING NETWORKS

FROM WATTS



to MEGAWATTS



..and everything in between!

When it comes to pulse capacitors and pulse-forming networks, many complexities in parameters and design factors must be considered. These specialized units must be designed and manufactured by a specialized organization. And because Sprague maintains a highly-technical special engineering section devoted exclusively to pulse capacitors and networks, it has been, from the very beginning, a major supplier of these complex units for radar equipment (ground, marine, aircraft, missile), tube testing, and similar pulse circuit applications.

This special engineering section performs four important functions: One group *designs* custom units in accordance with required parameters. Another group *builds* pulse capacitors and networks to these precise specifications. In another area, a group of specially-trained field engineers *provides application assistance* wherever needed. And yet another independent group *works toward the future* developing new materials, new design concepts, and new techniques for manufacture.

This concentration on pulse capacitors and pulse-forming networks has enabled Sprague to introduce product improvements such as heliarc sealing of cases, rugged alumina bushing assemblies, Fabmika® dielectric, and improved hermetic sealing of closures.

Save time and money by working with Sprague from the start. Application engineering services are available to you without obligation.

Write for Engineering Bulletin No. 10,001 to Technical Literature Section, Sprague Electric Co., 235 Marshall Street, North Adams, Massachusetts.

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THE MARK OF RELIABILITY

SPRAGUE COMPONENTS:
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HOW TO GET THE POWER TRANSISTORS YOU NEED?



JUST ASK DELCO. For even though our catalog lists only a handful of germanium power transistors, there is only a handful out of all those ever catalogued that we don't make. And those only because nobody ever asked for them.

We've made, by the millions, both large and small power transistors. Both diamond and round base. Both industrial and military types. And each in a wide variety of parameters that have proved themselves reliable in nearly every conceivable application.

You get Delco transistors fast. You get Delco transistors in any quantity. And for all their high reliability, you get them reasonably priced. All you have to do is contact our nearest sales office—and ask for them.

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Detroit, Michigan
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TRinity 3-6560

DELCO RADIO
Division of
General Motors
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DELAY LINES, INDUCTORS, FILTERS AND CHOKES...

ARNOLD IRON POWDER CORES CUT COSTS

ron powder cores are commonly speci-
ed for such applications as delay lines
illustrated below), inductors, filters and
lter chokes because of their inherent
ow cost. And Arnold cores are your
ogical choice, for the principal reasons
f superior dependability and the wide
election available to you.

Arnold's overall magnetic knowl-
dge, and unequalled facilities for
nanufacture and test, are of prime im-
ortance in assuring you a source of cores that are highly uniform, shipment after shipment. You'll find them dependable, not only in permeability and resultant inductance at high frequencies, but in high mechanical strength and dimensional accuracy as well.

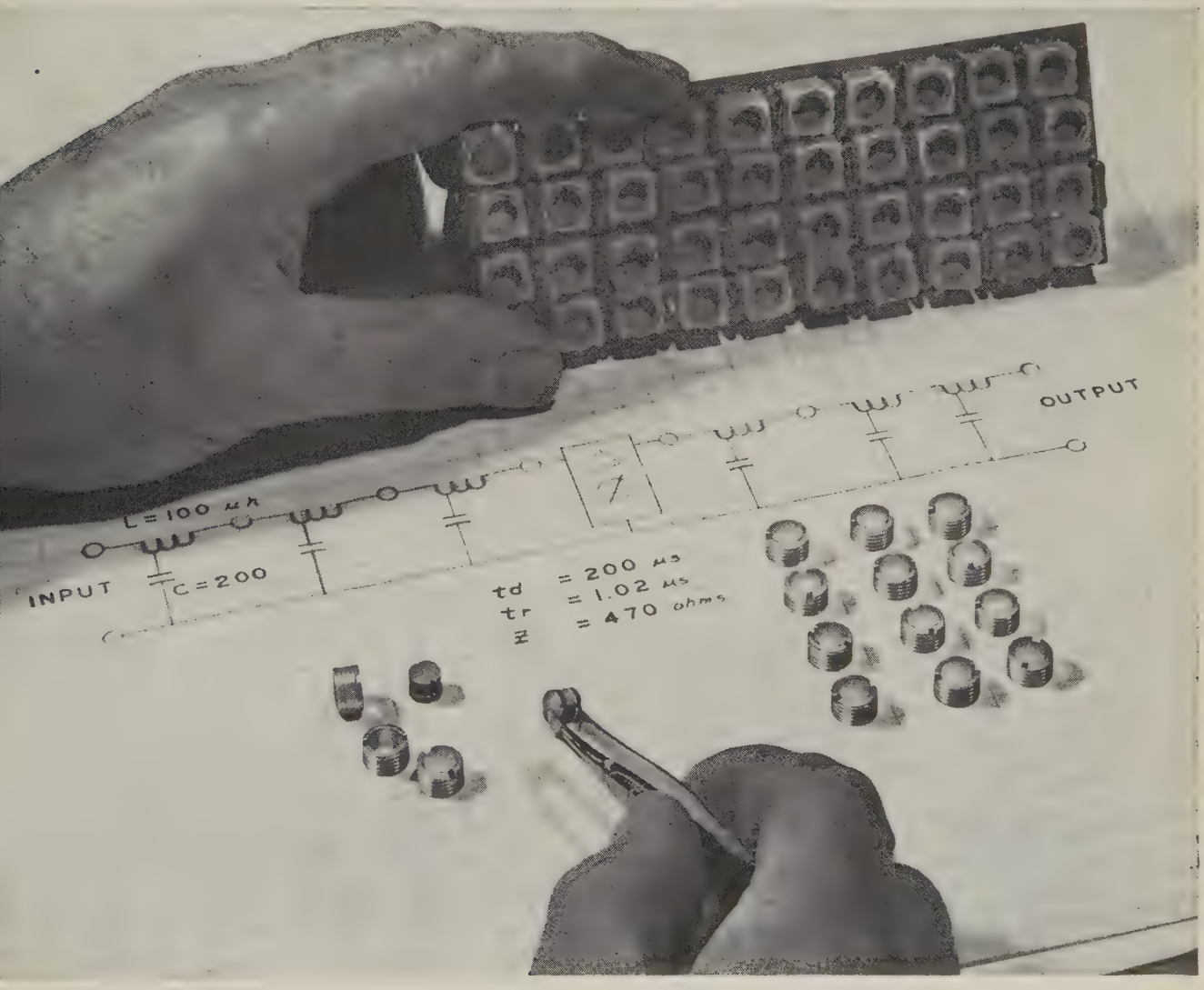
The Arnold line also offers a wider range of shapes and sizes of iron powder cores for your selection than any other one brand on the market. It includes bobbin cores, cups, toroids, plain, sleeve and hollow cores, threaded cores and insert cores, etc. Facilities for special cores to your order. Ask for new Bulletin PC-109A. ● Write *The Arnold Engineering Company, Main Office and Plant, Marengo, Illinois.*

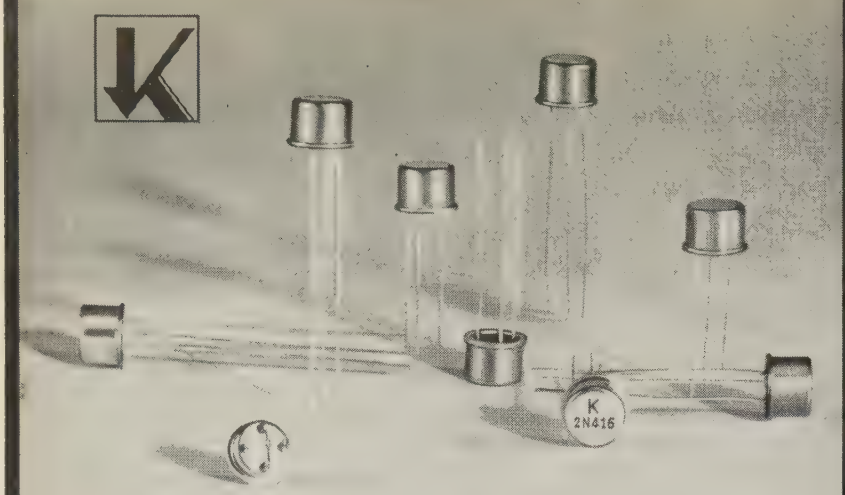
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2284





KEARFOTT TRANSISTORS PROVIDE HIGH RELIABILITY–CONSISTENT PERFORMANCE

HIGHEST POWER DISSIPATION OF ALL AVAILABLE GERMANIUM-ALLOY JUNCTION TRANSISTORS

Kearfott now offers a complete off-the-shelf series of TO-5 germanium-alloy PNP junction transistors. Their unexcelled electrical and mechanical reliability, precise electrical characteristics, and virtual insensitivity to temperature changes derive from Kearfott's intensive materials-and-methods control, plus complete, 100% functional testing. These factors add up to the consistent reliability, uniformity, extended service life, and repeatability of product performance which typify Kearfott semiconductors.

DESIGNED AND PRODUCED BY KEARFOTT SEMICONDUCTOR CORP. WEST NEWTON, MASS.

CHARACTERISTICS

Meet or exceed requirements of NAVORD OS9669B (R-212 Series) and MIL-S-19500B

All transistors tabulated below are available with maximum collector power dissipation of 200 mw.

2N123	2N404	2N520A	2N653
2N315	2N404A	2N521	2N658
2N315A	2N413	2N521A	2N659
2N316	2N414	2N522	2N660
2N316A	2N414A	2N522A	2N661
2N317	2N416	2N523	2N662
2N317A	2N425	2N523A	2N1017
2N394	2N426	2N578	2N1303
2N395	2N427	2N579	2N1305
2N396	2N428	2N580	2N1307
2N396A	2N519	2N581	2N1309
2N397	2N520	2N582	

Write for complete data

KEARFOTT DIVISION
GENERAL PRECISION, INC.

Little Falls, New Jersey

(Continued from page 32A)

vented a family of "3-D" radars manufactured by Hughes and now in service with the Armed Forces.

Radars based on this principle include Frescan, a system employed by the Navy on guided missile cruisers and destroyer leaders, and Frescanar, the "eyes" of Missile Monitor, an advanced mobile air defense system developed for the Army and now deployed in Europe.

Dr. Begovich joined Hughes as a research physicist in 1948 after receiving the Bachelor's, Master's and Doctor's degrees from the California Institute of Technology, Pasadena. He was an instructor in electrical engineering at the Institute from September, 1947 to June, 1951.

During his 18 years as an electronics engineer he has served as a research engineer for the War Metallurgy Committee and the War Production Board and as a consultant to the Weapons System Evaluation Group of the Joint Chiefs of Staff.

He is the author of technical papers on high frequency vacuum tube theory, electromagnetic radiation problems and radar detection theory.

❖

Dr. Frederick E. Brooks, Jr. (S'42–A'44–M'48–SM'54–F'58), former director of a 750-man research and development staff, has become Senior Scientist for Temco Electronics Division of Ling-Temco Electronics, Inc. He will serve as a consultant on several classified projects for the company.



F. E. Brooks, Jr.

During his 21 years in electronics, he has authored more than 30 technical papers, including titles such as "The Polyphase Regulator for Speed Control," and "The Effects of the Physical Parameters on the Bandwidth of a Folded Dipole." He holds a patent on the "Antenna System for Measuring Low Elevation Angles."

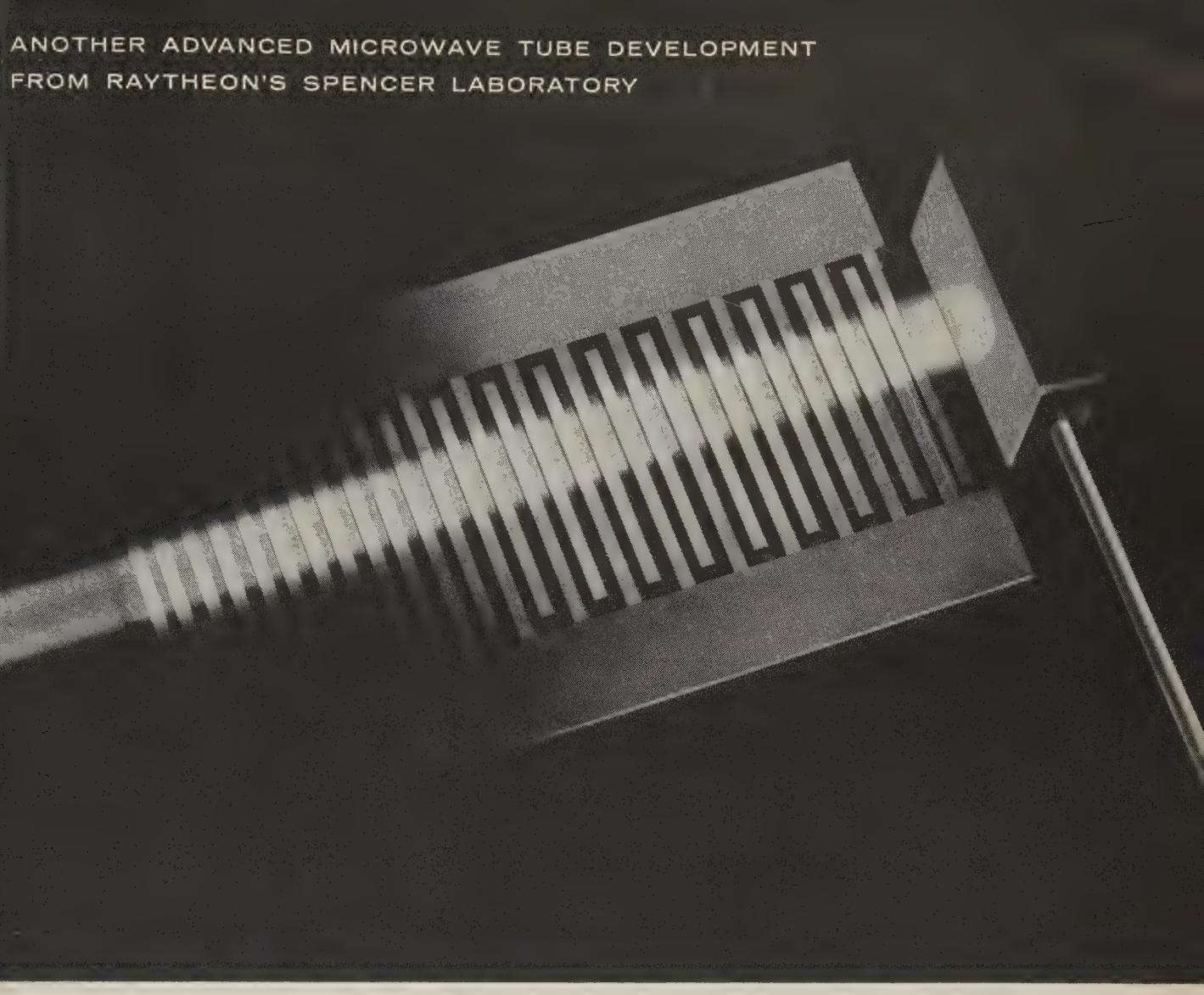
He is a member of three honorary societies—Tau Beta Pi, Eta Kappa Nu, and Sigma Xi, as well as Kappa Eta Kappa professional engineering fraternity, and the American Astronautical Society.

Joining the Texas Division of Collins Radio Company in July, 1957, he became director of research and development in January, 1959, a position he held until this month. He taught and directed work in the Electronic Engineering Research Laboratories at the University of Texas in Austin from November, 1943, until he joined Collins.

Dr. Brooks was born October 14, 1916, in Mineola, L. I., N. Y. He received the B.S. degree in electrical engineering from

(Continued on page 38A)

ANOTHER ADVANCED MICROWAVE TUBE DEVELOPMENT
FROM RAYTHEON'S SPENCER LABORATORY



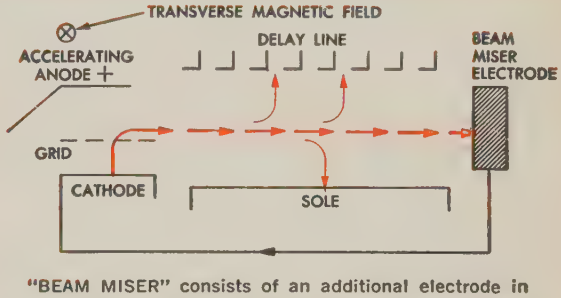
How new Raytheon "BEAM MISER" boosts efficiency in crossed field devices

Unique depressed collector greatly improves efficiency of "M" BWO's and crossed field amplifiers.

"Beam Miser" is Raytheon's newest advance in crossed field oscillator and amplifier design. With it are opened many new design possibilities for applications requiring voltage tunability or bandwidth plus high reliability and efficiency.

Incorporating the "Beam Miser" into existing crossed field tubes will yield improved performance and *will not require any mechanical or electrical changes in equipment.*

Write for further information on Raytheon developments in crossed field devices. Microwave & Power Tube Division, Raytheon Company, Waltham 54, Massachusetts. In Canada: Waterloo, Ontario.



"BEAM MISER" consists of an additional electrode in the crossed field device which collects a portion of the spent beam at cathode potential and returns it to the cathode by means of an internal conductor.

RAYTHEON COMPANY

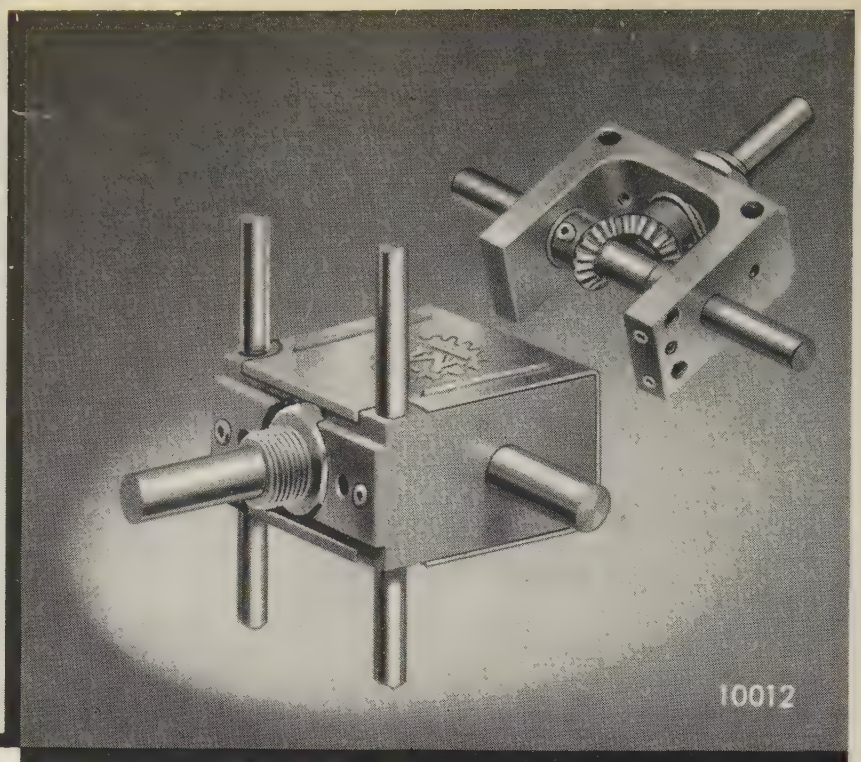
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RAYTHEON

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Extremely compact, with provisions for many methods of mounting. Ideal for operating potentiometers, switches, etc., that must be located, for short leads, in remote parts of chassis. No. 10012 for ¼ inch shafts. No. A012 Miniature for ⅛ inch shafts.

JAMES MILLEN MFG. CO., INC.

MALDEN

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AN ANTI-MISSILE MISSILE RADAR...



is kept on the alert with the help of an Eastern pressurizer dehydrator system. This compact unit feeds a flow of controlled, dry air to the wave guide of the powerful acquisition radar — at pressures higher than the atmosphere, so that the ambient can't sift in through leaks. As a result, moisture can't condense on high-voltage elements; dangerous arc-overs are eliminated. The dehydrating pressurization pack is completely self-contained, circulates air through alternate, self regenerating capsules of silica gel which need never be replaced. For additional information, write for Bulletin 370.

Eastern Aviation Products

EASTERN INDUSTRIES, INC.

100 Skiff Street, Hamden 14, Conn.

West Coast Office: 4203 Spencer St., Torrance, Calif.

IRE People

(Continued from page 36A)

the University of Kansas, Lawrence, in January, 1940. As a teaching Fellow, he also studied at Armour Institute in Chicago, Ill., and Yale University, New Haven, Conn. He received the Doctor of Engineering degree from Yale in June, 1944.

❖

Leslie J. Cook (SM'56) has joined Electro-Optical Systems, Inc., as Manager of the Fluid Physics Division.



L. J. Cook

In this capacity, he will direct the division's research and development programs in high density plasma, electric propulsion, and re-entry physics. A major activity within this division is the development of an ion propulsion engine, successors of which will be used in space vehicle propulsion and satellite orientation applications.

Prior to joining EOS, he was Manager of West Coast Operations for the Perkin-

(Continued on page 42A)



STATIC OR DYNAMIC TESTING

MINCOM SERIES G-100 RECORDER-REPRODUCER

FM and analog testing, RF or closed circuit data storage with Mincom reliability—all in the day's work for this superb, all-purpose general instrumentation system: the **Mincom G-100 Magnetic Tape Recorder/Reproducer.** Direct response is 200 cps to 300 kc at 60 ips. FM response at 60 ips is dc to 20 kc (broadband), dc to 10 kc (standard). Fourteen tracks in one rack. All-transistored card system record/reproduce modules, interchangeable for FM or analog. Greater dynamic range, built-in calibration, lower power requirements. Interested? Write for complete specifications.

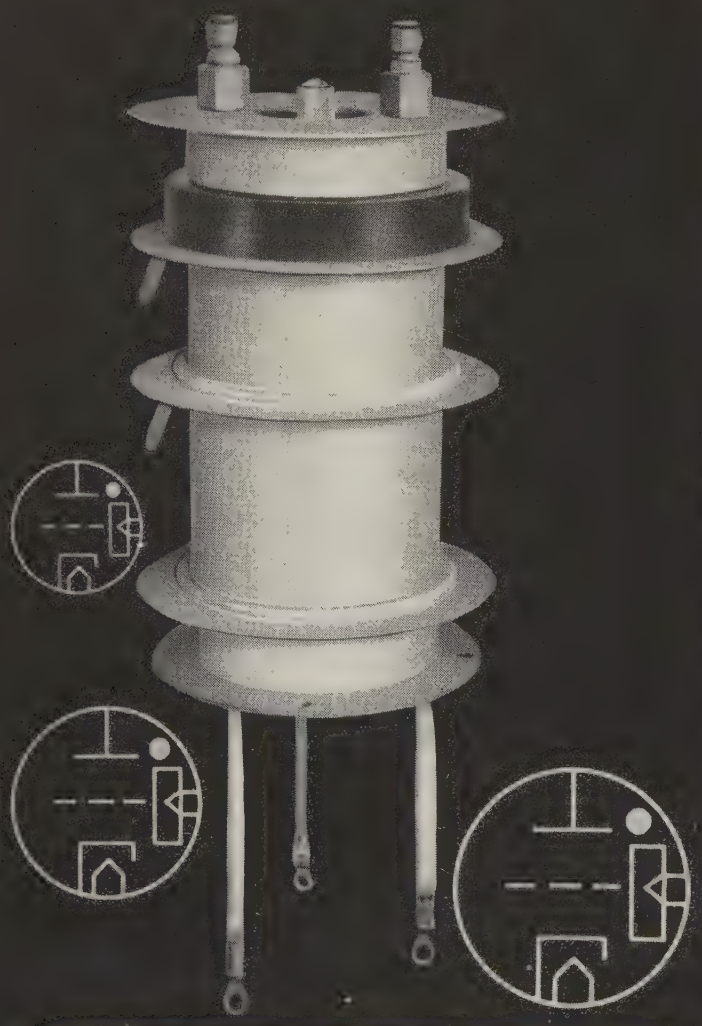
3M COMPANY ... WHERE RESEARCH IS THE KEY TO TOMORROW

MINCOM DIVISION MINNESOTA MINING AND MANUFACTURING COMPANY

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Progress In Hydrogen Thyratrons

55 x 10^9 ANODE DISSIPATION FACTOR



G-E Power Tube Department Products Also Include:

- Ignitrons
- Traveling-wave tubes
- Magnetrons
- Metal-ceramic tetrodes
- High-power duplexers
- High-power waveguide filters
- Klystrons
- Thermionic converters

Highest Registered Rating Now Available from G.E. In an Air-cooled Tube

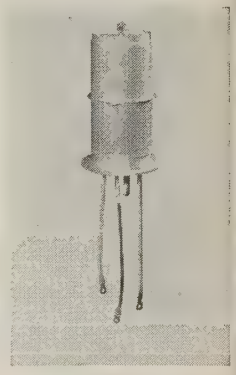
The latest addition to General Electric's expanding line of hydrogen thyratrons is now available for pulse applications such as radar modulators and linear accelerators. Developed under U. S. Army Signal Corps contract, the GL-7890 achieves an anode dissipation factor of 55 x 10^9 and has a peak anode voltage rating of 40 kv. The tube can now be operated water-cooled or air-cooled at full ratings.

COMING: INCREASED CURRENT AND VOLTAGE CAPACITY

Now in the late stages of development, the Z-5212 will further increase voltage and current-carrying capacity in hydrogen thyratrons. Peak anode voltage rating for this tube will be 50 kv with an average current rating of 8 amp. General Electric's Power Tube Department will welcome your requests for technical data on the Z-5212.

TEMPERATURE INDICATING DEVICE ON GL-7390A

The first high-power ceramic-metal hydrogen thyratron, General Electric's GL-7390, is now being built to MIL specifications. A modified version of this tube, the GL-7390A, is equipped with an integral anode temperature indicator for convenient readings. Both the GL-7390 and the GL-7390A have ratings of 33-kv peak anode voltage and 4-amp average current.



GL-7390A

HYDROGEN THYRATRON BULLETIN AVAILABLE

For a comprehensive analysis of the theory and application of hydrogen thyratrons, write to the Power Tube Department, General Electric Company, Schenectady, N. Y. Ask for Bulletin PT-49. To order, or obtain more information on hydrogen thyratrons, contact your nearest Power Tube sales office. Phone numbers are listed below.



265-09-9545-8481-36

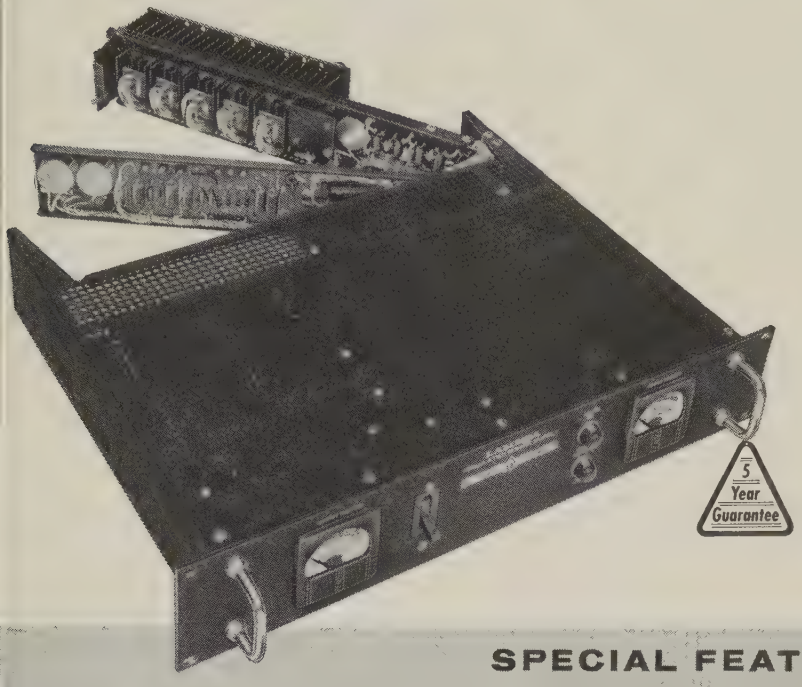
POWER TUBE DEPARTMENT

GENERAL ELECTRIC

TELEPHONE TODAY—Syracuse, OL 2-5102 . . . Clifton, N. J., GR 3-6387 . . . New York City, WI 7-4065 . . . Washington, D. C., EX 3-3600 . . . Chicago SP 7-1600 . . . Dayton, BA 3-7151 . . . Orlando, Fla., GA 4-6280 . . . Los Angeles, GR 9-7765.

LAMBDA

Convection Cooled Transistorized Regulated Power Supplies



LA SERIES

0- 34 VDC	5 AMP
0- 34 VDC	10 AMP
0- 34 VDC	20 AMP
20-105 VDC	2 AMP
20-105 VDC	4 AMP
20-105 VDC	8 AMP
75-330 VDC	0.8 AMP
75-330 VDC	1.5 AMP
75-330 VDC	3 AMP

SPECIAL FEATURES

- Convection Cooled—No internal blowers or filters—maintenance free
- Ambient 50°C
- No Voltage Spikes or overshoot on "turn on, turn off," or power failure
- Short Circuit Proof
- Remote programming over Vernier band
- Hermetically-sealed transformer designed to MIL-T-27A
- Easy Service Access
- Constant Current Operation—Consult Factory
- Guaranteed 5 years

CONDENSED DATA

DC OUTPUT (Regulated for line and load)

Model	Voltage Range (1)	Vernier Band (2)	Current Range (3)	Price (4)
LA 50-03A	0- 34 VDC	4 V	0- 5 AMP	$ 395
LA100-03A	0- 34 VDC	4 V	0-10 AMP	510
LA200-03A	0- 34 VDC	4 V	0-20 AMP	795
LA 20-05B	20-105 VDC	10 V	0- 2 AMP	350
LA 40-05B	20-105 VDC	10 V	0- 4 AMP	495
LA 80-05B	20-105 VDC	10 V	0- 8 AMP	780
LA 8-08B	75-330 VDC	30 V	0- 0.8 AMP	395
LA 15-08B	75-330 VDC	30 V	0- 1.5 AMP	560
LA 30-08B	75-330 VDC	30 V	0- 3 AMP	860

Regulation (line).....Less than 0.05 per cent or 8 millivolts (whichever is greater). For input variations from 105-140(5) VAC.

Regulation (load).....Less than 0.10 per cent or 15 millivolts (whichever is greater). For load variations from 0 to full load.

Ripple and Noise.....Less than 1 millivolt rms with either terminal grounded.

Temperature Coefficient.....Less than 0.025%/°C.

(1) The DC output voltage for each model is completely covered by four selector switches plus vernier range.

(2) Center of vernier band may be set at any of 16 points throughout voltage range.

(3) Current rating applies over entire voltage range.

(4) Prices are for unmetered models. For metered models add the suffix "M" and add $30.00 to the price.

(5) Except for LA50-03A, LA100-03A, LA200-03A which have AC input voltage of 100-130 VAC. 105-140 VAC available upon request at moderate surcharge.

AC INPUT 105-140 VAC, 60(5) ± 0.3 cycle(6)

(6) This frequency band amply covers standard commercial power line tolerances in the United States and Canada. For operation over wider frequency band, consult factory.

Size

LA 50-03A, LA20-05B, LA 8-08B	3½" H x 19" W x 14⅜" D
LA100-03A, LA40-05B, LA15-08B	7" H x 19" W x 14⅜" D
LA200-03A, LA80-05B, LA30-08B	10½" H x 19" W x 16½" D

Send for new Lambda Catalog 61

LA116A

LAMBDA ELECTRONICS CORP.

515 BROAD HOLLOW ROAD, HUNTINGTON, L. I., NEW YORK 516 MYRTLE 4-4200

hi-var*
CAPACITORS
...OFFER 75% REDUCTION IN WEIGHT/VOLUME

Hi-Var capacitors have prime application in lightweight airborne equipments. Ideal for potted and oil immersed circuitry from sea level to 100,000 feet. High voltage radial terminals are space saving with long, heavy horizontal creepage path minimizing corona — yet permitting highest voltage in miniature circuitry.

(Bulletin 10-TB-60)

CLEAR-PASS* CAPACITORS

A new subminiature feed-thru RF interference suppressor, Dearborn Clear-Pass capacitors combine maximum insertion loss over a broad band of radio frequencies with minimum size/weight. Uniquely designed thread neck effectively eliminates inductance between noise source and output terminals and minimizes contact resistance to chassis — thus obtaining optimum insertion loss.

(Bulletin 11-TB-60)

PULSE FORMING NETWORKS

Using Deltaply* laminated dielectrics, Dearborn's PFN provide reductions in volume/weight as well as extended life and superior retrace characteristics. Units have application which require the use of "E" type high voltage networks and produce rectangular shaped pulses to near perfection.

(Bulletin 9-TB-60)

WRITE FOR THE ABOVE BULLETINS

Dearborn
ELECTRONIC LABORATORIES, INC.
P. O. Box 3413 • Orlando, Florida • TErrace 8-5400

IRE People

(Continued from page 38A)

Elmer Corporation. Before his association with Perkin-Elmer, he was a member of the Senior Staff at Thompson Ramo-Wooldridge, Inc., where he was Manager of the Instrumentation Department and of the Systems Engineering Department. Prior associations were as a physicist at the Radiation Laboratory of the University of California, Berkeley, and at the U. S. Navy Bureau of Ordnance, Pearl Harbor, Hawaii.

Mr. Cook received the A.B. degree in physics from the University of California, Berkeley, in 1938, and was a graduate student at that university until 1941. He holds several patents in the fields of metallurgy, chemistry, and physical electronics. He is a member of the American Physical Society.

❖

Dr. Raymond DuHamel (S'47–A'52–M'57) has joined Hughes Aircraft Company's ground systems group in Fullerton, Calif., as a senior staff scientist in the Radar Laboratory. He will report to Dr. N. Yaru, Associate Manager of the Radar Laboratory.

Before joining Hughes, he served as Assistant Director of the Research Division, Collins Radio Company, Cedar Rapids,

(Continued on page 44A)

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Features of the Model 102B are: decade gains from 0.1 to 1000, selectable bandwidths of 2 cps to 150 kc and 2 cps to 1.7 mc, and a 5-volt, 50-ohm output for scopes and recorders. Other features include:

- **input impedance** of 400 megohms, shunted by 3 $\mu\mu$f.
- **low noise level,** below 10 μv from 10 cps to 150 kc at maximum gain.
- **gain accuracy** of 1% at midband for all gain settings.
- **rise time** of 0.3 μ sec at highest gain.
- **two accessory** low capacitance probes available.
- **Price** — $335.00

For full details write:

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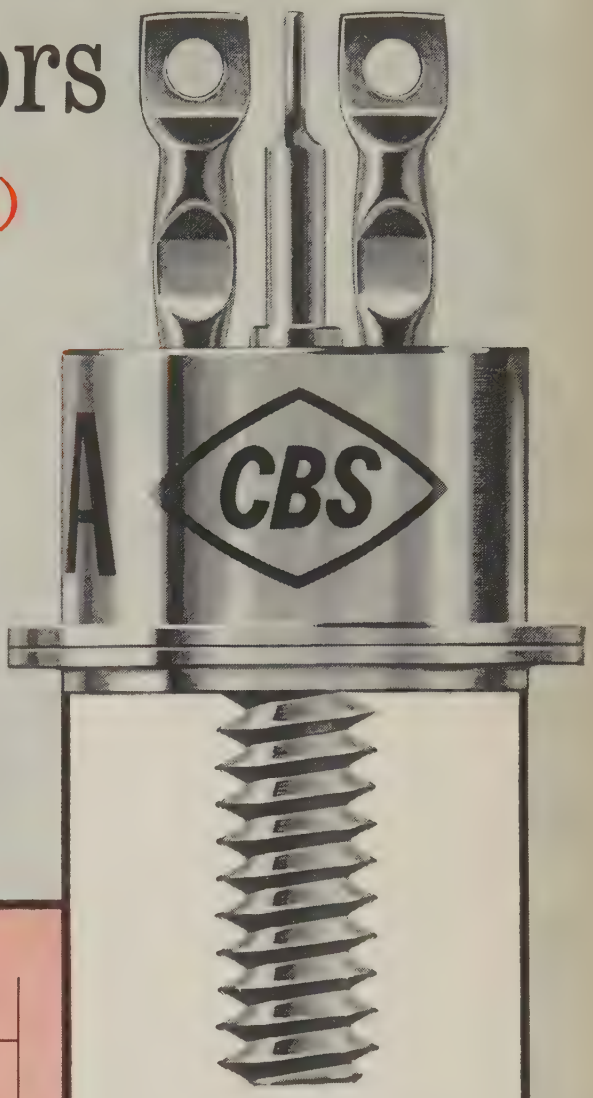
New Improved CBS PNP Power Transistors

2N538(A) • 2N539(A) • 2N540(A)
FEATURE MORE POWER, LESS WEIGHT, LESS SPACE

The CBS 2N538(A), 2N539(A) and 2N540(A) have a maximum dissipation of 30 watts at a base mounting temperature of 25 deg. Centigrade. Yet, each transistor weighs less than 5 grams and requires only 1/3 square inch of chassis space.

Compact and rugged, these hermetically-sealed CBS PNP Germanium Power Transistors are ideal for military and industrial power applications demanding high reliability. They are especially suited for servo motor controls, power amplifiers, converters, power supply regulators and low-speed power switches.

Note the major characteristics and advantages. Call or write today for complete technical data and delivery information from your local sales office or Manufacturer's Warehousing Distributor.



ELECTRICAL CHARACTERISTICS

Type	Max. VCBO	Min. V_{CE} ($d=1$)	hFE ($I_C=2A$, $V_{CE}=-2V$) Min.	hFE Max.	V_{BE} ($I_C=2A$, $V_{CE}=-2V$) Min.	V_{BE} Max.	Gp (mhos) ($I_C=2A$, $V_{CE}=-2V$) Min.	Gp Max.
2N538	—80	—55	20	50	1.33	3.33		
2N538A	—80	—55	20	50	1.33	3.33	17.5	52
2N539	—80	—55	30	75	1.00	2.50		
2N539A	—80	—55	30	75	1.00	2.50	35	105
2N540	—80	—55	45	113	0.75	1.88		
2N540A	—80	—55	45	113	0.75	1.88	71	213

All types have: Max, collector current, 3.5 amps; junction temperature, --65 to +95°C; max, saturation voltage 0.6 volts ($I_C=2A$, $I_B=200$ mA). Minimum alpha cutoff frequency is 200 KC ($I_C=100$ MA, $V_{CE}=-4$ volts); max, thermal resistance, 2.2°C/W.

CBS PNP Power Transistors with an improved industrial male package offer:

- Single, sturdy 8-32 mounting stud
- Matched glass-to-metal seal for greater mechanical strength and resistance to thermal shock
- Rugged welded construction through the selection of matched materials having excellent welding properties
- Typical leakage three to five times lower than specification limits.
- High dissipation with minimum size
- High collector-to-base voltage
- High collector-emitter breakdown voltage
- Wide range of operating and storage temperatures

CBS semiconductors®

More Reliable Products through Advanced Engineering

CBS ELECTRONICS, Semiconductor Operations, Lowell, Massachusetts
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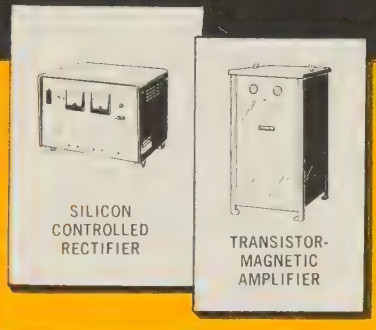
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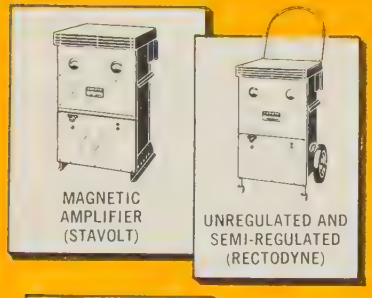
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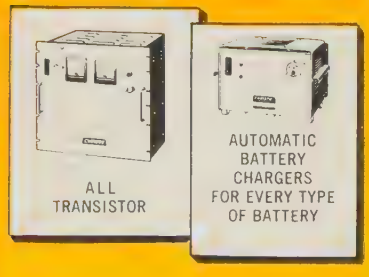
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(Continued from page 42A)

Iowa. He previously had worked in the University of Illinois Department of Electrical Engineering as Research Assistant Professor and Associate Director of the Antenna Laboratory.

He has had 14 years experience in the field of antenna and holds several patents, with others pending, for his work on log periodic antennas.

He is a member of the IRE Professional Group on Antennas and Propagation, as well as the Professional Group on Microwave Theory and Techniques.

Dr. DuHamel received the Bachelor, Master and Doctorate degrees in electrical engineering from the University of Illinois, Urbana.

❖

The appointment of **Paul G. Edwards** (SM'47–F'60) to head The Mitre Corporation's Communications Department has been announced by R. R. Everett, Vice President—Technical Operations.

Prior to joining Mitre, Mr. Edwards was Director of Development at the Merrimack Branch of the Bell Telephone Laboratories, where he was responsible for the final development of telephone transmission systems. During his 39 years of service with Bell Systems he worked on a variety of communications systems, including transmission, sonar and guided missile control systems.

He is a Fellow of the American Institute of Electrical Engineers. He is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu honorary societies, and holds the B.E.E. degree and the E.E. degree from Ohio State University.

❖

Appointment of **Robert H Cranshaw** (A'56) as Marketing Manager of the Systems Division of Electro-Mechanical Research, Inc., has been announced. He has a broad knowledge of military systems and advanced projects marketing, and his previous outstanding experience in sales and marketing management positions is expected to contribute strongly to EMR Systems Division sales. The EMR Systems Division supplies telemetry and data reduction systems to major missile and space vehicle manufacturers and government agencies. In addition, the Division's advanced capabilities embrace the fields of communications, optics, infrared and ultraviolet techniques, and similar areas.



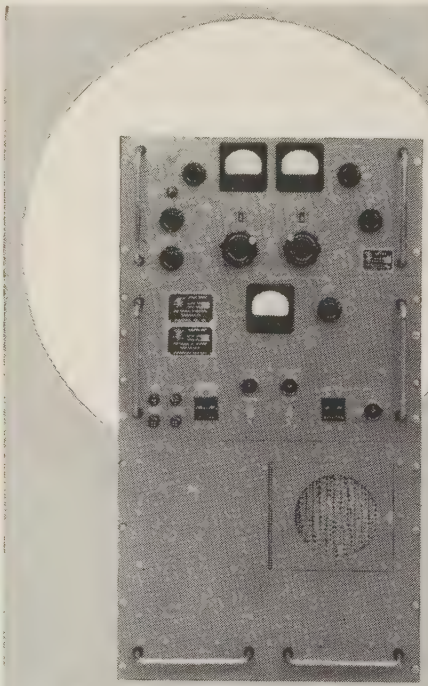
R. H. CRANSHAW

He obtained the B.S.M.E. degree with honors from the Virginia Polytechnic Institute, Blacksburg, in 1948. Following

(Continued on page 46A)

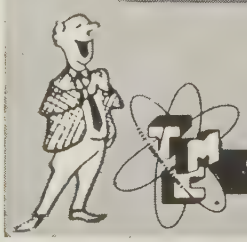
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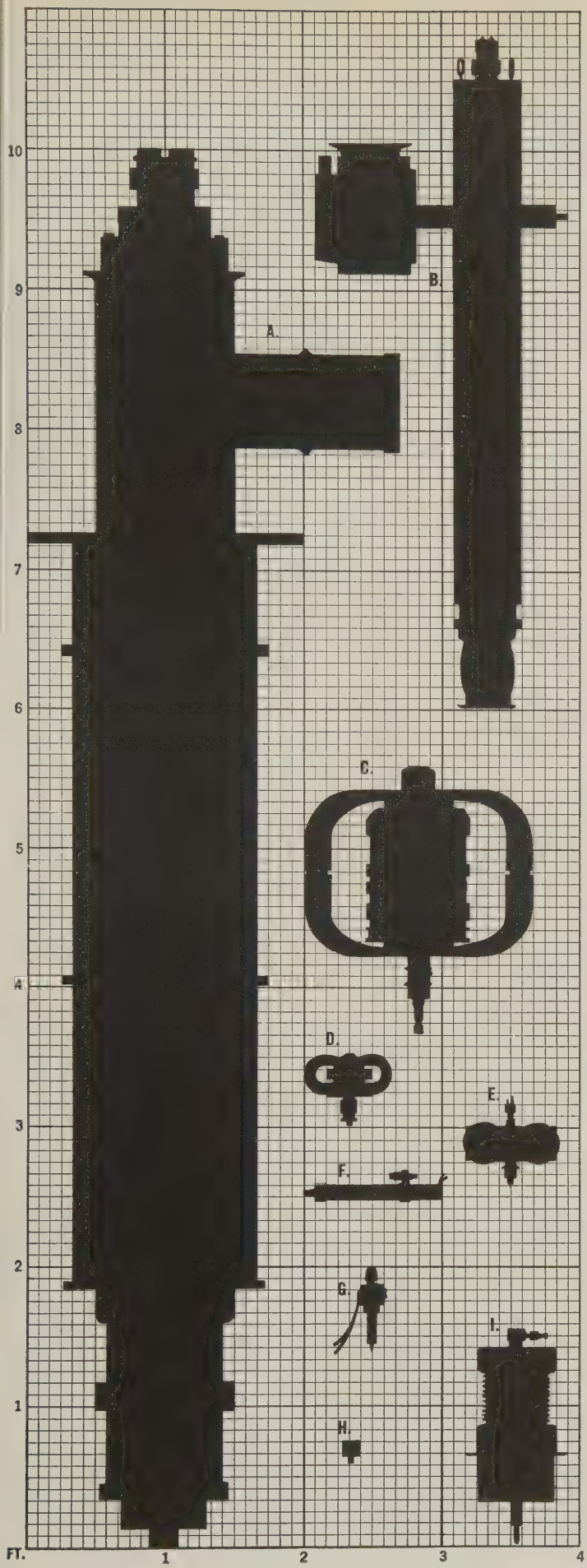
The TMC Model PAL-1K is a conservatively rated Linear Power Amplifier delivering 1000 Watts PEP SSB or 1000 Watts CW and FS throughout the frequency range of 2 to 32 mcs.

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C. L-3455 HIGH POWER MAGNETRON: A new magnetron delivering a minimum of 2 megawatts peak power at 406-450 mc. with a .002 duty cycle.

D. L-3458 HIGH TEMPERATURE PULSE MAGNETRON: Provides long life operation at ambient temperatures in excess of 662°F. Many hours of 900°F. operation have been achieved in X-band tests.

E. L-3629 FLOATING DRIFT TUBE KLYSTRON: High power, water-cooled klystron oscillator fixed tuned at 33,000-37,000 mc. Power output: 15 watts CW minimum. Other tubes available for immediate delivery from 12-4 mm. wavelength.

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G. MICROTRON: The L-3189, one-kilowatt CW magnetron, is accompanied in package form by an electromagnet and filter assembly, high voltage and filament and isolation transformers. Only 6-second warm-up. Two year warranty for domestic microwave cooking.

H. L-3430 CUBE MINIATURE MAGNETRON: A one-kilowatt miniature magnetron, fixed tuned at 9300 ± 30 mc, weighing less than 9 ounces and no bigger than a normal X-band waveguide flange. Developments at other power levels and frequencies are planned.

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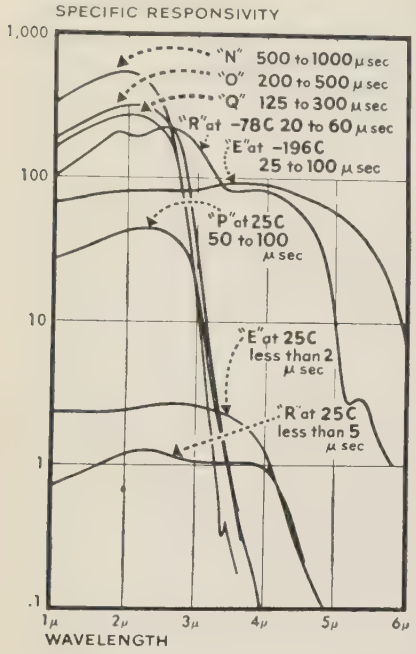


For information on our tube line, exclusive of classified types, send for the 1961 Electron Tube Condensed Catalog. Write to: Marketing Dept., Electron Tube Division, 960 Industrial Road, San Carlos, California

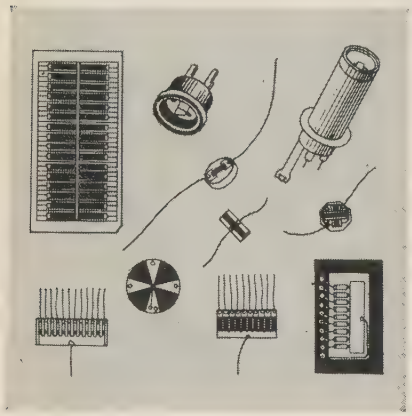
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(Continued from page 44A)

graduation, he joined the General Electric Company as a Test Engineer. He was transferred later to the International General Electric Company as a sales engineer, and eventually moved up to the position of Washington, D C., Representative in charge of the sales of all GE products for export sale in this area. He then moved to the GE Light Military Equipment Department in Utica, N. Y., first as District Manager of Advanced Space Projects in the Air Force in the Washington office, then successively as Manager of Advanced Development Sales, and Manager of Guidance and Computation Product Sales. In these positions he had considerable responsibility in sales and marketing of research and development, and airborne electronic products of all types

Mr. Cranshaw is a member of the AOA, the AFCEA, and the AFA. He is an active member of the IRE Professional Group on Military Electronics. He is past Chairman of the Washington Chapter of the PGMIL; has been active in all PGMIL National Conventions, and was President of the 4th National Convention. He is presently serving as a member of the National Administrative Committee of PGMIL, and Chairman of the Guest Speaker Committee of the Seventh Na-

(Continued on page 50A)

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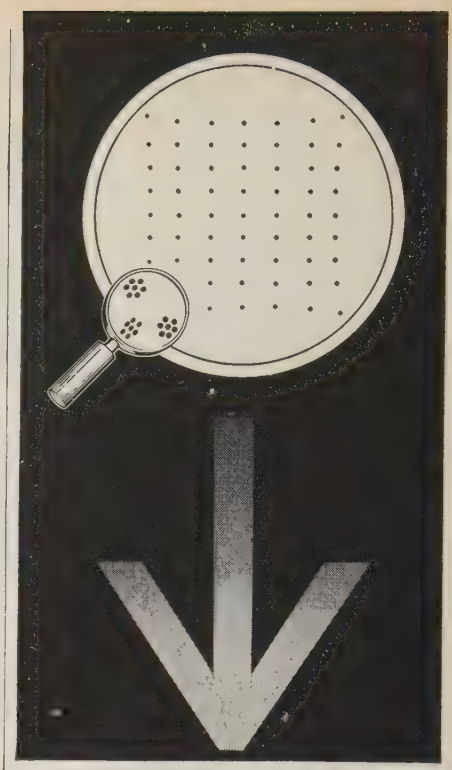
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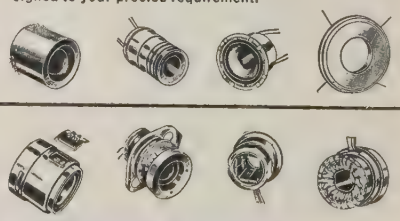
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Mr. George M. Kirkpatrick, Chairman, General Electric Co., Syracuse, N.Y.

39 Transactions, *6, & *9, and Vol. 2, No. 1-3; Vol. 4, No. 1, 2, 3; Vol. 5, No. 2, 3, 4; Vol. 6, No. 1, 2, 4; Vol. 7, No. 1, 2, 3, 4; Vol. 8, No. 1.

Antennas and Propagation

Annual fee: $6.

Technical advances in antennas and wave propagation theory and the utilization of techniques or products of this field.

Dr. Harry Fine, Chairman, Applied Propagation Branch FCC, Washington, D.C.

36 Transactions, *Vol. AP-2, No. 2; AP-4, No. 4; AP-5, No. 1-4; AP-6, No. 1, 2, 3, 4; AP-7, No. 1, 2, 3, 4; AP-8, No. 1, 2, 3, 4, 5, 6; AP-9, No. 1, 2, 3.

Audio

Annual fee: $2.

Technology of communication at audio frequencies and of the audio portion of radio frequency systems, including acoustic terminations, recording and reproduction.

Prof. Cyril M. Harris, Chairman, Columbia University, 632 W. 125 St., New York 27, N.Y.

57 Transactions, *Vol. AU-1, No. 6; *Vol. AU-2, No. 4; Vol. AU-3, No. 1, 3, 5; Vol. AU-4, No. 1, 5-6; Vol. AU-5, No. 1, 2, 3, 4, 5, 6; AU-6, No. 1, 2, 3, 4, 5, 6; AU-7, No. 1, 2, 3, 4, 5, 6; AU-8, No. 1, 2, 3, 4, 5, 6; AU-9, No. 1.

Automatic Control

Annual fee: $3.

The theory and application of automatic control techniques including feedback control systems.

Mr. John M. Salzer, Chairman, 909 Berkeley St., Santa Monica, Calif.

12 Transactions, PGAC-3-4-5-6, AC-4, No. 1, 2, 3; AC-5, No. 1, 2, 3, 4; AC-6, No. 1.

Bio-Medical Electronics

Annual fee: $3.

The use of electronic theory and techniques in problems of medicine and biology.

Mr. George N. Webb, Chairman, Dept. of Med. Biophysical Div., Johns Hopkins Hospital, Baltimore 5, Md.

20 Transactions, 8, 9, 11, 12; ME-6, No. 1, 2, 3, 4; ME-7, No. 2, 3, 4; BME-8, No. 1, 2.

Broadcast & Television Receivers

Annual fee: $4.

The design and manufacture of broadcast and television receivers and components and activities related thereto.

Mr. Robert R. Thalner, Chairman, Sylvania Home Electronics, Batavia, N.Y.

28 Transactions, *7, 8; BTR-1, No. 1-3, BTR-2, No. 1-2-3; BTR-3, No. 1-2; BTR-4, No. 2, 3-4; BTR-5, No. 1, 2; BTR-6, No. 1, 2, 3; BTR-7, No. 1.

Broadcasting

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Broadcast transmission systems engineering, including the design and utilization of broadcast equipment.

Mr. Raymond F. Guy, Chairman, NBC, 30 Rockefeller Plaza, New York 20, N.Y.

19 Transactions, No. 10, 11, 12, 13, 14; BC-6, No. 1, 2, 3; BC-7, No. 1, 2.

Circuit Theory

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Dr. James H. Mulligan, Jr., Chairman, College of Eng., New York University, New York 53, N.Y.

30 Transactions, CT-4, No. 3-4; CT-5, No. 1, 2, 3, 4; CT-6, No. 1, 2, 3, 4; CT-7, No. 1, 2, 3, 4; CT-8, No. 1.

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Radio and wire telephone, telegraph and facsimile in marine, aeronautical, radio-relay, coaxial cable and fixed station services.

Mr. Ralph L. Marks, Chairman, Rome Air Dev. Center, Griffiss AFB, N.Y.

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Mr. Floyd E. Wenger, Chairman, Headquarters ARDC, Andrews AFB, Washington 25, D.C.

23 Transactions, CP-4, No. 1, 2, 3, 4; CP-5, No. 1, 2, 3, 4; CP-6, No. 1, 2, 3, 4; CP-7, No. 1, 2, 3, 4; CP-8, No. 1.

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13 Transactions, Vol. E-1, No. 3, 4; E-2, No. 1, 2, 3, 4; E-3, No. 1, 2, 3, 4; E-4, No. 1.

Electron Devices

Annual fee: $3.

Electron devices, including particularly electron tubes and solid state devices.

Mr. Willis A. Adcock, Chairman, Texas Instruments Co., Dallas 9, Tex.

33 Transactions, *Vol. ED-1, No. 3, 4; ED-3, No. 2, 4; ED-4, No. 2, 3, 4; ED-5, No. 2, 3, 4; ED-6, No. 1, 3; ED-7, No. 2, 3, 4; ED-8, No. 1, 2, 3.

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Annual fee: $4.

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Dr. A. A. Cohen, Chairman, Remington-Rand Univac, St. Paul 16, Minn.

37 Transactions, EC-6, No. 2, 3; EC-7, No. 1, 2, 3, 4; EC-8, No. 1, 2, 3, 4; EC-9, No. 1, 2, 3, 4; EC-10, No. 1.

Engineering Management

Annual fee: $3.

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Mr. T. W. Jarmie, Chairman, Engineered Electronics, 1441 East Chestnut Ave., Santa Ana, Calif.

21 Transactions, EM-3, No. 2; EM-4, No. 1, 3, 4; EM-5, No. 1-4; EM-6, No. 1, 2, 3; EM-7, No. 1, 2, 3, 4; EM-8, No. 1.

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John M. Kinn, Jr., Chairman, IBM Journal, 545 Madison Ave., New York, N.Y.

9 Transactions, Vol. EWS-1, No. 2; EWS-2, No. 1, 2, 3; EWS-3, No. 1; EWS-4, No. 1, 2.

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26 Transactions, PGIT-4, IT-1, No. 3; IT-2, No. 3; IT-3, No. 1, 2, 3, 4; IT-4, No. 1, 2, 3, 4; IT-5, No. 1, 2, 3, 4; IT-6, No. 1, 3, 4, 5; IT-7, No. 1, 2.

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Mr. Harvey W. Lance, Chairman, Natl. Bureau of Standards, Boulder, Colo.

19 Transactions, PGI-4, Vol. 1-6, No. 2, 3, 4; Vol. 1-7, No. 1, 2; Vol. 1-8, No. 1, 2; Vol. 1-9, No. 1, 2, 3.

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Mr. Tore N. Anderson, Chairman, EMT Corp., Syosett, Long Island, N.Y.

36 Transactions, MTT-4, No. 3; MTT-5, No. 3, 4; MTT-6, No. 1, 2, 3, 4; MTT-7, No. 2, 3, 4; MTT-8, No. 1, 2, 3, 4, 5, 6; MTT-9, No. 1, 2, 3.

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The electronics sciences, systems, activities and services germane to the requirements of the military. Aids other Professional Groups in liaison with the military.

Mr. Willie L. Doxey, Chairman, EC Dept., USASRDL, Fort Monmouth, N.J.

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20 Transactions, NS-1, No. 1; NS-4, No. 2; NS-5, No. 1, 2, 3; NS-6, No. 1, 2, 3, 4; NS-7, No. 1, 2-3, 4; NS-8, No. 1, 2.

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7 Transactions, No. 2-3, 4, 5, 6, PEP-5, No. 1.

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Origin, effect, control and measurement of radio frequency interference.

Mr. Harold E. Dinger, Chairman, Naval Research Lab., Washington 25, D.C.

2 Transactions, RFI-1, No. 1, RFI-2, No. 1.

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Techniques of determining and controlling the quality of electronic parts and equipment during their manufacture.

Mr. P. K. McElroy, Chairman, General Radio Co., West Concord, Mass.

20 Transactions, *3, 5, 10, 11, 12, 13, 14, 15; RQC-9, No. 1, 2, 3; RQC-10, No. 1.

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Mr. Kenneth V. Uglow, Chairman, Electro-Mechanical Research Inc., Sarasota, Fla.

17 Transactions, TRC-1, No. 2-3; TRC-2, No. 1; TRC-3, No. 2, 3; TRC-4, No. 1; SET-5, No. 1, 2, 3, 4; SET-6, No. 1, 2, 3-4; SET-7, No. 1.

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10 Transactions, PGUE, 5, 6, 7; UE-7, No. 1, 2; UE-8, No. 1.

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17 Transactions, 5, 8, 9, 10, 11, 12, 13; Vol. VC-9, No. 1, 2, 3; Vol-10, No. 1.

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SPECIALTY CAPACITORS • DELAY LINES

RF INTERFERENCE TESTING • SYSTEMS ENGINEERING

IRE People

(Continued from page 46A)

tional Communication Symposium sponsored by the Professional Group on Communication Systems.

❖

Dr. Robert M. Fano (S'41–A'45–SM'48–F'54), Professor of Electrical Communication at the Massachusetts Institute of Technology, Cambridge, has been elected to the Board of Directors of Adcole Corporation, Cambridge, Mass., manufacturers of electronic systems.



R. M. Fano

Dr. Fano has been on the staff at the Massachusetts Institute of Technology since 1941, and has served as Leader of the Radar Techniques Group of MIT's Lincoln Laboratory. He has been a consultant to the Department of Defense and various industrial laboratories and is a Fellow of the American Academy of Arts and Sciences. He is the author of a number of papers and textbooks in the fields of electromagnetic theory and information theory.

❖

It was recently announced that **Donald G. Fink** (A'35–SM'45–F'47) has been appointed Vice President for Research of Philco Corporation.



D. G. Fink

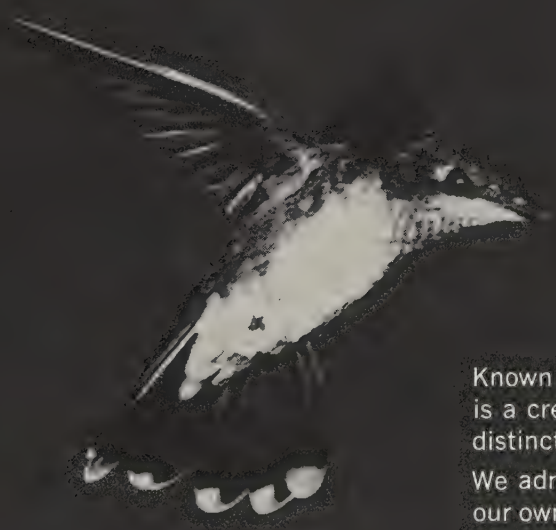
Formerly Director of Research and General Manager of the Research Division, he is internationally known in the electronic industry. Employed at Philco since 1952, when he became Director of Research for consumer product programs, he was former Editor-in-Chief for *Electronics* magazine. He is author of five books about electronics, television and radar, and editor of four others—including a volume on color television standards.

Mr. Fink was Editor of PROCEEDINGS OF THE IRE in 1956 and 1957, and during 1958 was President of the Institute of Radio Engineers.

He is Fellow of the AIEE and of SMPTE. His honors include Medal of Freedom (1948), the Presidential Certificate of Merit, receipt of the Radio Fall Meeting Plaque (1951), the SMPTE Journal Award (1956) and the American Technologist Award (1958).

Since 1956, he has served as member of the Army Scientific Advisory Panel, and is Vice Chairman of the Communications and Electronics Subpanel.

(Continued on page 54A)



Known to rout hawks a hundred times his size, the hummingbird is a creature of courage. But when he takes this risk, it is with a distinct advantage. His powers of flight are matched by none.

We admire his style. And we share the philosophy. Knowing that our own capabilities are highly distinctive, we too believe that they are a thing to be used with boldness. Two years ago, Fairchild pioneered commercial production of diffused silicon Mesa transistors. They became the industry's most widely copied types. But we developed direct replacements — silicon PLANAR transistors (PLANAR diodes too were developed) — another step forward. Our newly introduced PLANAR EPITAXIAL devices and MICROLOGIC elements continue the progress.

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Photo from the book "HUMMINGBIRDS" by C. H. Greenewalt; © American Museum of Natural History

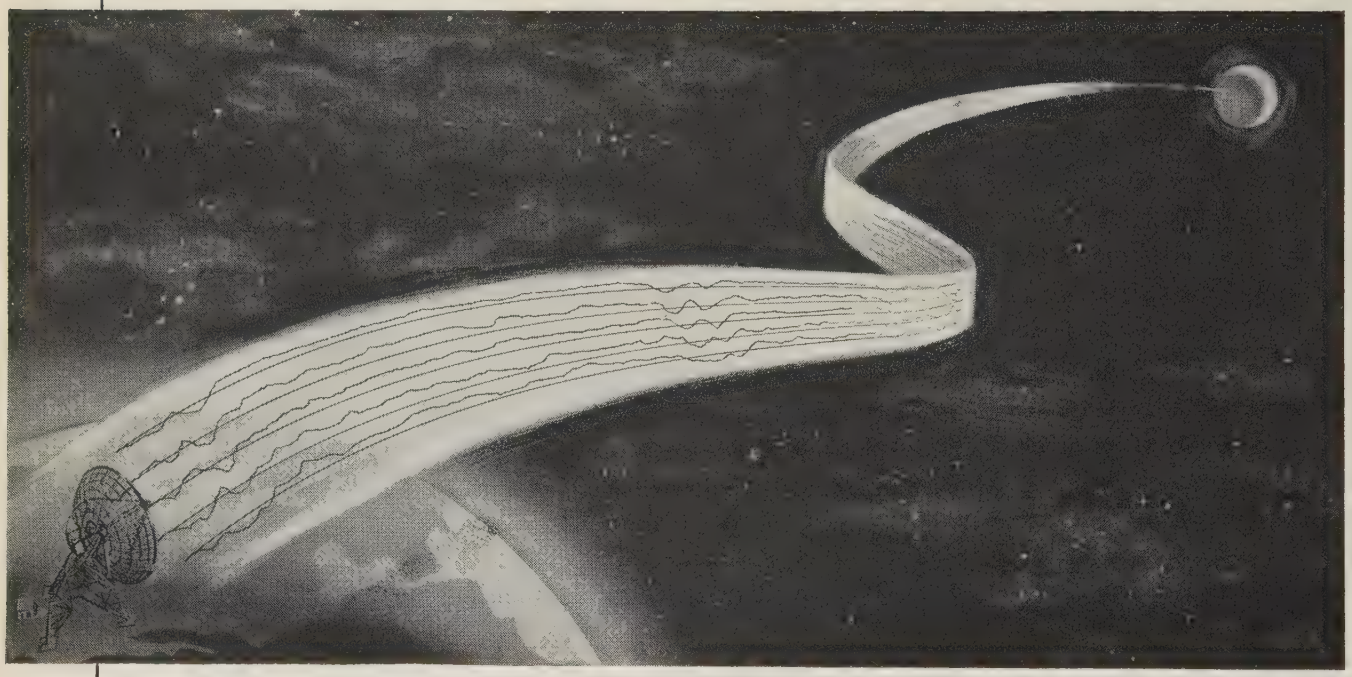
Whispers... from Venus

From March 10 to May 10, 1961, JPL's Deep Space Instrumentation Facility at Goldstone, California, conducted an important radar bounce experiment directed at the planet Venus and hundreds of hours of scientific data were collected. The results obtained helped establish the United States as the leader in the new science of planetary radar astronomy.

Prior to this experiment, the Astronomical Unit (AU) contained an uncertainty factor of 60,000 miles which JPL scientists have now been able to reduce to 1,000 miles—possibly 100 miles—as one of the results of this effort.

Establishing a more accurate value for the AU will enable JPL to measure the exact distance to Venus prior to the launching of the first U. S. Venus probe.

One of the most important conclusions to be drawn from this successful experiment is the knowledge that we can now design a planetary radar observatory capable of almost continuous surveillance of Venus, Mars, Mercury and Jupiter. Therefore, March 10, 1961 marks the beginning of a new era in space technology and exploration.



This scientific accomplishment is only one of the many research programs in progress at JPL under its space exploration responsibility to NASA. These extensive investigations into the science and technology of the space environment offer real and stimulating incentives to uninhibited scientists and engineers with searching minds. JPL needs such men, who look forward to rewarding careers in this uncharted field.

Resumes and inquiries directed to A. R. Locke, Manager of Professional Placement, will receive immediate attention.

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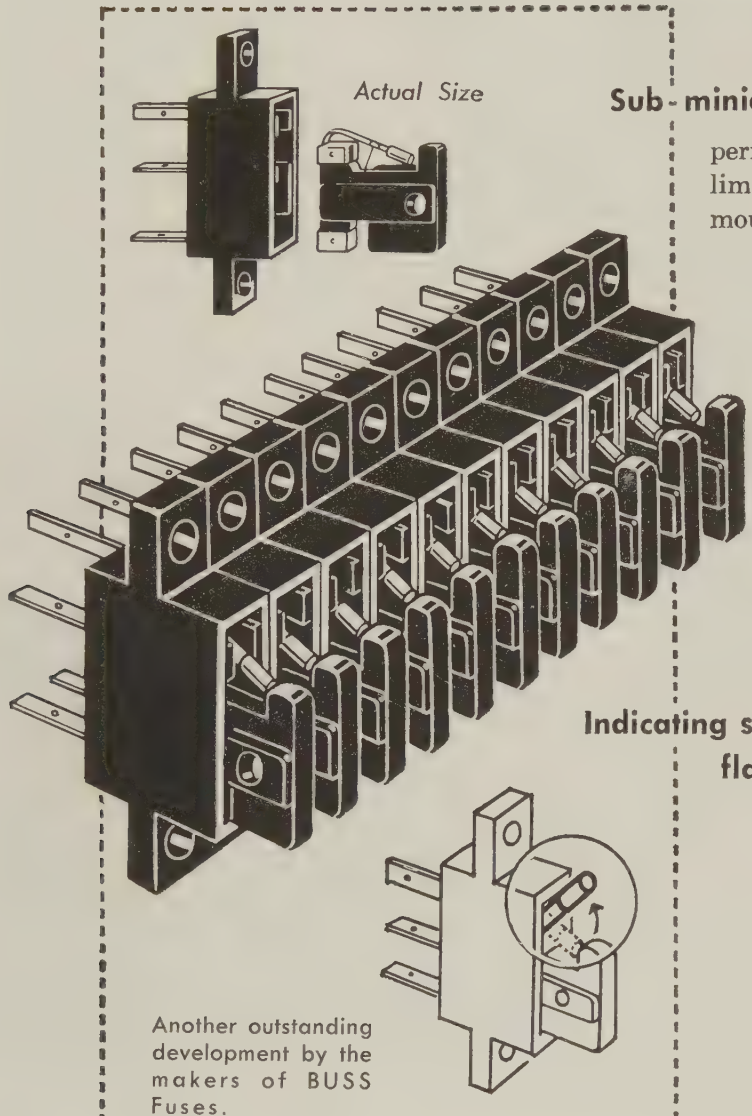
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Sub-miniature design

permits multiple mounting of fuses in limited space. Fuseholders can be mounted on ¼ inch horizontal centers.

Fuse and holder combination readily adaptable for use in equipment operating at 300 volts or less, such as: communication equipment, business machines, computors, control equipment or other multiple circuit apparatus where space is at a premium.

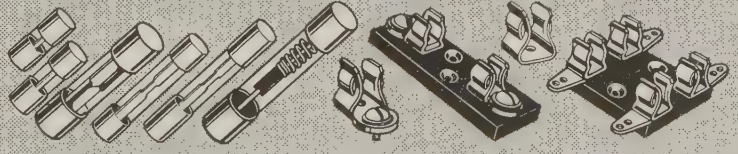
Indicating spring flashes color-coded flag when fuse opens

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Indicator spring also makes contact with an alarm circuit so, it can be used to flash a light—or sound audible signal on fuse panel or at a remote location.

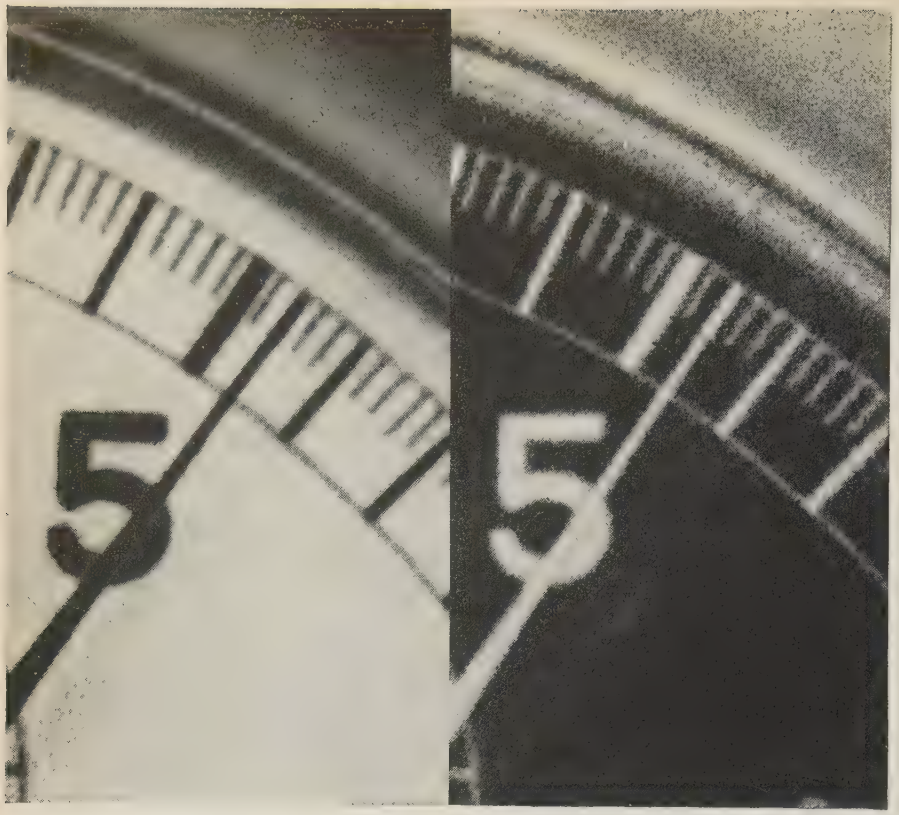
Ask for bulletin GMCS on BUSS GMT fuses and HLT holders.

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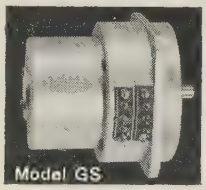


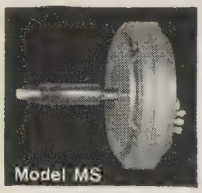
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Model GS. Incorporating an integral induction-start motor, the phonic-wheel-type GS can be operated from a vacuum tube amplifier on frequencies from 60 to 3600 cps. It may be operated single phase in the plate circuit of a single-ended amplifier or as a two-phase motor when driven by push-pull amplification. Motor current is app. 75 milliamperes per phase, output up to 1/100 hp.

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IRE People

(Continued from page 50A)

He has served as Chairman of the Coordination Committee of the National Stereophonic Radio Committee, as well as Vice-Chairman of the National Television System Committee, from 1950–1952.

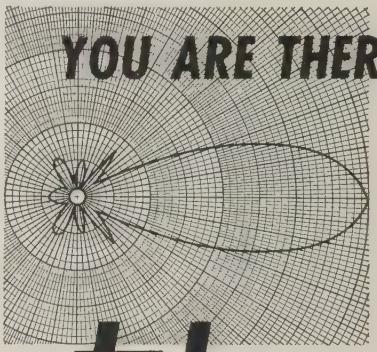
From 1943–1945, he was expert consultant to the Office of Secretary of War. He has served also as consultant to the Belgian Government for television standardization, and as consultant to the U. S. Navy's Bureau of Ships during the Bikini atom bomb tests in 1946. Other consulting activities (1949–1956) include those to the U. S. State Department, on that organization's Television Standardization Committee.

Mr. Fink is author of many technical papers for the primary journals in the field of electronics. He was awarded the degree of B.Sc. in electrical communications from the Massachusetts Institute of Technology, Cambridge, in 1933, and received the M.Sc. degree in electrical engineering in 1942 from Columbia University, New York. N. Y.

❖

Herbert S. Evander (S'48–A'50–M'55–SM'57) has been appointed Manager of Transistor Products for the Semiconductor Division of Hughes Aircraft Company.

(Continued on page 56A)



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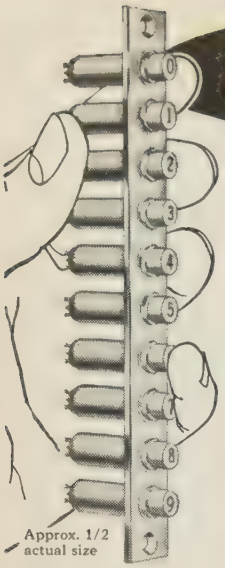
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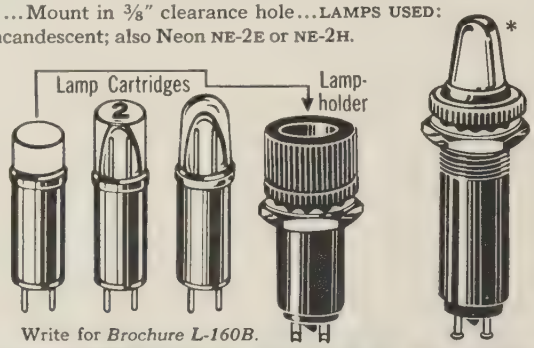
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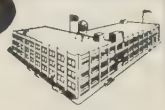
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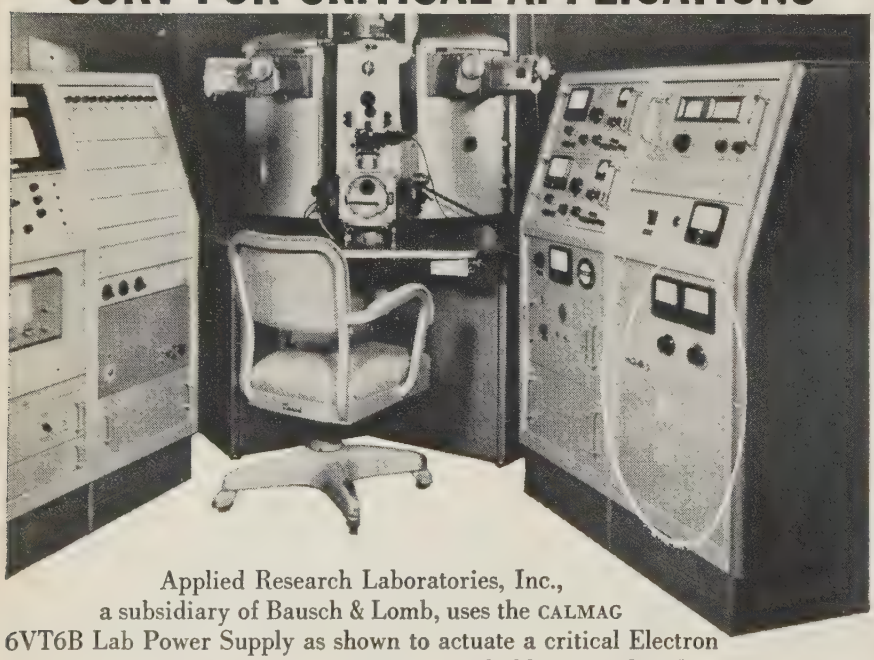
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IRE People

(Continued from page 54A)

He joined the Division as Manager of Transistor Sales in September, 1960. He later was named manager of product sales for transistors, rectifiers and special products. In his new post, he will manage transistor engineering, manufacturing, marketing and related test and inspection operations.

Before joining Hughes, he was Marketing Manager, Semiconductor Division, Tung-Sol Electric Company, Newark, N. J.

He received the Bachelor's and Master's degrees in electrical engineering from Newark College of Engineering, Newark, N. J. He is a member of the Tau Beta Pi fraternity and of the American Management Association.

❖

Selection of **Dr. Eugene G. Fubini** (A'36–SM'46–F'54) of Brookville, L.I., N.Y. as Director of Research, Office of the Director of Defense Research and Engineering, was announced recently by the Department of Defense.



E. G. FUBINI

He is the first to serve in this new position, and will act as a principal deputy to the Director of DRE.

The new Directorate includes the presently-organized Offices of Electronics, Guided Missiles, Atomic, Biological and Chemical Warfare; Aeronautics, Science, Fuels, Materials and Ordnance; and Maintenance Engineering.

Since January, 1960 he has been Vice President of Research and Systems Engineering of AIL, Division of Cutler-Hammer, Deer Park, L.I., N. Y. He joined AIL in 1945 following civilian service with the military services during World War II.

In 1943 and 1944 he was a scientific consultant and technical observer to the U. S. Army and U. S. Navy in the European Theater of Operations, where he participated in the establishment of electronic reconnaissance and jamming capabilities for the invasion of Italy and Southern France. During 1944–1945, he was in England with the U. S. Eighth Air Force in charge of electronic reconnaissance and counter-measures, and served also, in 1945, as a special consultant for ECM to the Office of the Air Communications Officer of the War Department.

During the over-all period of 1942–1945, he was a Research Associate of the Harvard University Radio Research Laboratory.

Dr. Fubini received the Doctor of Physics degree in Rome, Italy. He is a former lecturer at Harvard University, Cambridge, Mass.

❖

(Continued on page 58A)

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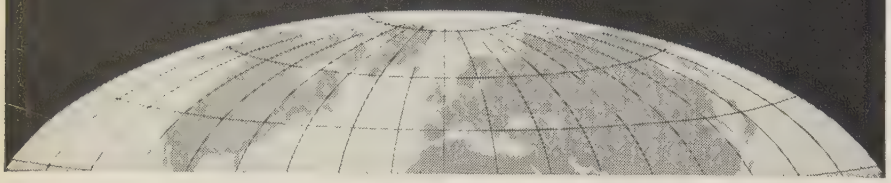
TYPE	Breakdown ① Voltage (BV)	Maximum Reverse Current (μA) 25°C	150°C	Test Voltage ②	Forward Current (Min. mA @ IV)	Reverse Recovery Max. (mμsec) ③	Capacitance at V_R=0 (pf) ④	Rectification ⑤ Efficiency
SP100	75	0.1	100	50	10	2	2	45%
SP101	30	.025	50	20	100	2	2	45%
SP106	125	.025	50	100	100	2	2	45%
IN914A	100	.025	50	20⑥	20	4	4	45%
IN916A	100	.025	50	20⑥	20	4	2	45%

① Breakdown Voltage at 100 μA. ② Voltage at which Reverse Current measurements were taken. ③ Switching I_F= 10 mA to V_R=6.0 V R_L=100 ohms recovery to 1 mA. ④ Measured at 1 megacycle. ⑤ Measured at 100 megacycles using MIL-STD-19500 test circuit. ⑥ Reverse leakage when measured at —75 Volts and 25°C shall not exceed 5 μA.

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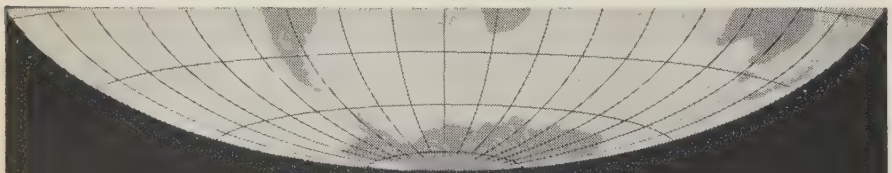
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H28

IRE People

(Continued from page 56A)

Appointment of **Rear Admiral William L. Freseman** (SM'47), USN (Ret.), to a new post of Assistant to the President of Radio Engineering Laboratories, Inc. (REL), communications subsidiary of Dynamics Corporation of America, has been announced.



W. L. FRESEMAN

An authority in the fields of communications and radar, he previously was Vice President of International Standard Engineering, Inc., a subsidiary of International Telephone and Telegraph Corporation, and also Manager of the IT&T Projects Group. He was the founder, in 1952, of the Radar Research Laboratory of the University of Miami, Coral Gables, Fla., which he headed as Director, and also served as Professor of Electrical Engineering at the University. His prior naval career of more than 25 years encompassed a number of major naval communications assignments, as well as line commands through World War II.

He received the B.S. degree from the United States Naval Academy, Annapolis,

(Continued on page 60A)

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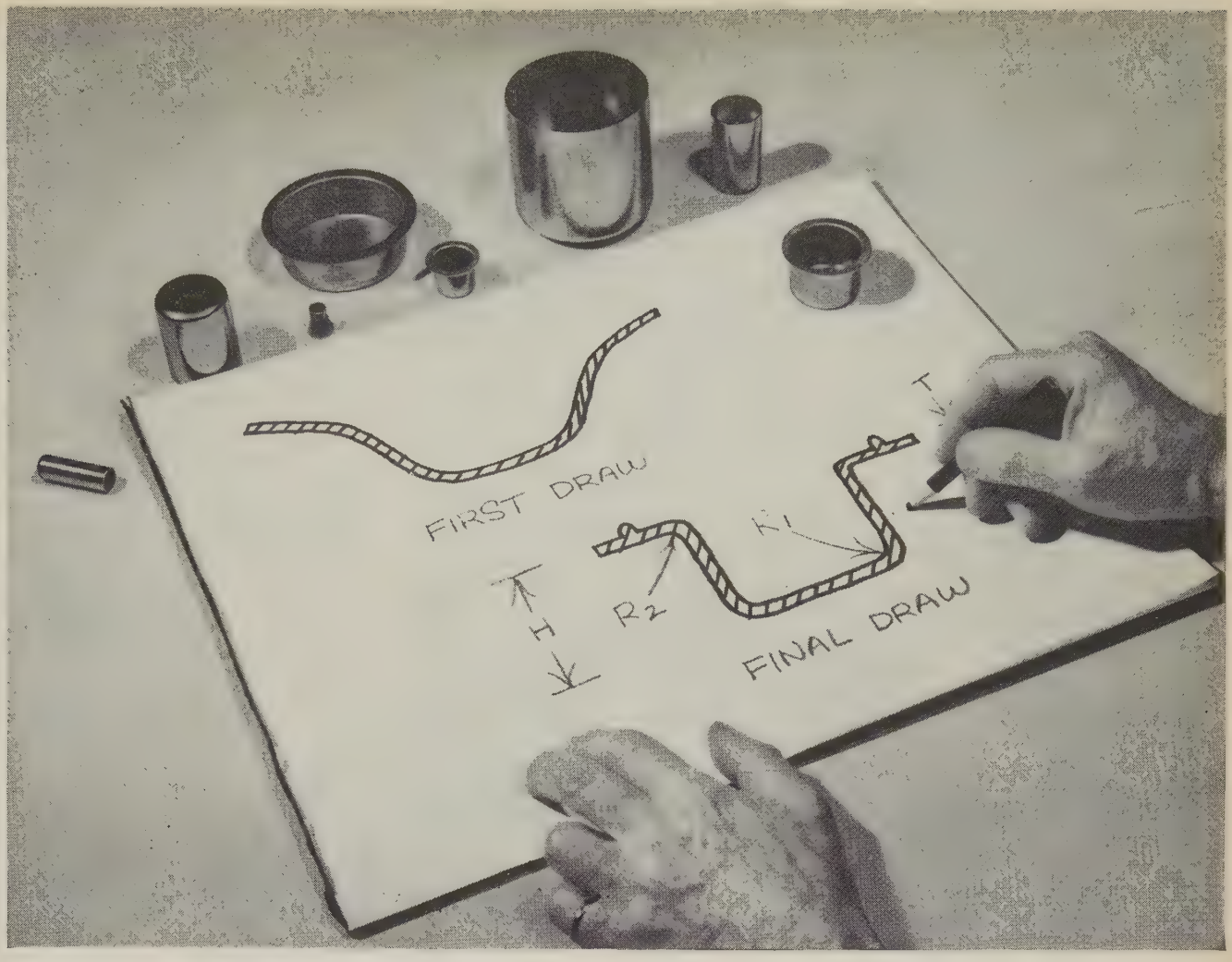
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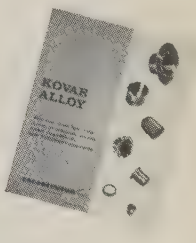
1. On the initial draw, punch radius should be a minimum of four times the material thickness. Reduce successively on re-draws.
2. Inside radii at the corners on the final draw should be not less than the thickness of the metal.
3. Sharper radii, if absolutely essential, should be produced by a subsequent coining operation.
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IRE People

(Continued from page 58A)

Md., in 1922, the M.S. degree from Harvard University, Cambridge, Mass., in 1929, and the Certificate from the Naval War College in 1935.

Admiral Freseman is a member of the Radio Club of America and of the Armed Forces Communications and Electronics Association. He is author and co-author of a number of technical reports and is the co-author of a textbook on radar meteorology.

❖

C. E. Rutherford, President of Rutherford Electronics Company, Culver City, Calif., announces that **Walter L. Schwartz** (S'55–M'56) has joined the firm and will be responsible for the development of transistor pulse equipment.



W. L. SCHWARTZ

He earned the Bachelor of Electrical Engineering degree at Cooper Union, New York, N. Y., and the Master of Science degree from U.C.L.A., where he was a National Science Foundation Fellow.

Experienced in pulse and digital circuits and systems through positions at Electronic Transformer Company, Lockheed Missile Systems Division, Litton Industries, and General Motors, Mr. Schwartz is a registered professional engineer in the State of California. He is also a member of Tau Beta Pi, and a lecturer at Los Angeles State College of Applied Arts and Sciences, Los Angeles, Calif.

❖

Dr. Richard T. Smith (A'47–M'55–SM'61) has been appointed Westinghouse Professor of Electrical Engineering at Virginia Polytechnic Institute, Blacksburg. He is currently Associate Professor of Electrical Engineering at the University of Texas, Austin. He received the B.S. and M.S. degrees from Lehigh University, Bethlehem, Pa., and the Ph.D. degree from the Illinois Institute of Technology, Chicago.

He spent six years with the General Electric Company, working mainly on electro-mechanical power systems for aerospace vehicles, before joining the University of Texas three years ago.

Dr. Smith is a member of the IRE Professional Group on Circuit Theory, the American Institute of Electrical Engineers and the American Rocket Society, as well as Tau Beta Pi and Sigma Xi. He has written many technical papers and serves as a member of the Aerospace Transportation Committee of the AIEE. He has been a consultant to Lear, Inc., and to Jack & Heintz.

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(Continued on page 118A)

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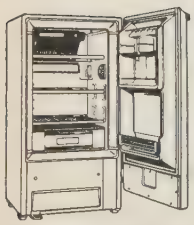
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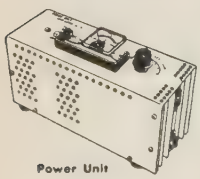
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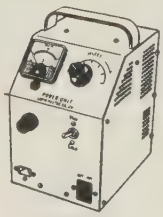
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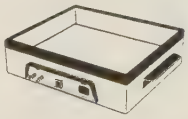
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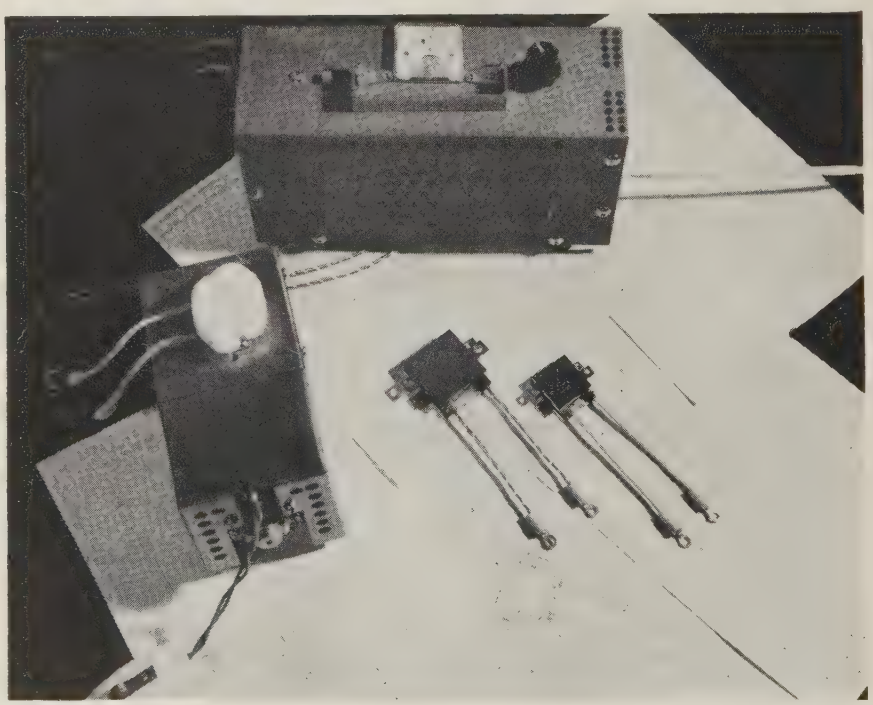
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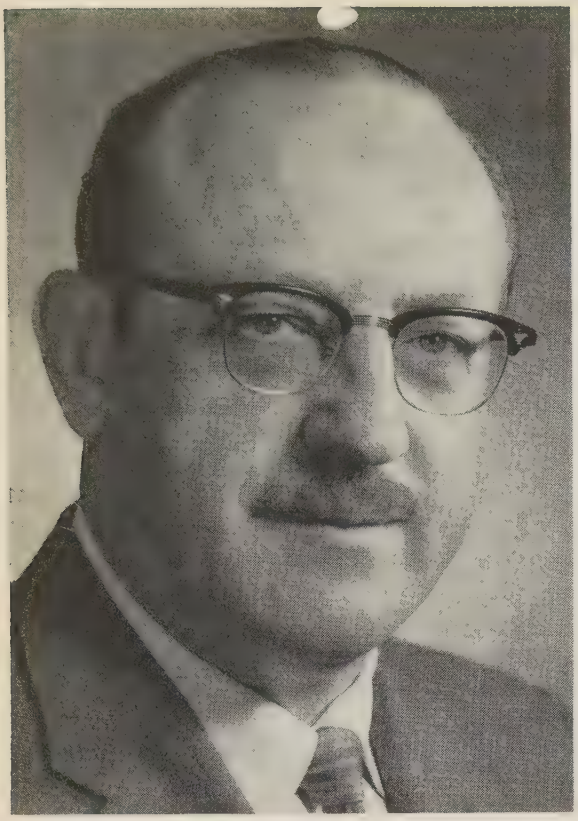
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L. C. Van Atta

Director, 1961–1963

Lester C. Van Atta (M'42–SM'43–F'52) was born in Portland, Ore., in 1905. He received the B.A. degree in physics from Reed College, Portland, in 1927, and the Ph.D. degree from Washington University, St. Louis, Mo., in 1931. From 1931–1932 he was with Princeton University, Princeton, N. J., in the Physics Department; from 1932–1940 he was with the Massachusetts Institute of Technology, Cambridge, also in the Physics Department; and from 1940–1945 he headed the Antenna Group of the MIT Radiation Laboratory. He headed the Antenna Research Branch at the Naval Research Laboratory from 1945–1950, and since that time he has been with the Hughes Aircraft Company, Culver City, Calif. He has held the following positions with the company: Head of the Microwave Laboratory, Associate Director of the Research Laboratories, and, most recently, Director of Technical Information and Education. He is presently on professional leave from Hughes as Special Assistant for Arms Control to Dr. H. F. Cook in the Office of the Secretary of Defense.

He has been active in military research and development since 1940, at the MIT Radiation Laboratory, the Naval Research Laboratory, and at Hughes Aircraft Company. In addition, he has served on the Research and Development Board, as Chairman of the Panel on Antennas and Propagation (1946–1949). More recently, he participated in a series of WSEG studies of continental air defense (1956–1958), in a series of PISGAH and other research and development conferences for the Army (1957–1959), in two ARGUS studies at Lawrence Radiation Laboratory (1958–1959), and on the Gaither Committee (1959).

At Hughes Aircraft Company he has directed systems studies such as the Hemispherical Scan System for the Navy and the ICBM Passive Defense System for the Air Force—systems based on electronic beam scanning techniques.

His technical fields of specialization have included high resistors, electron scattering in gases, high voltage and high vacuum engineering, production and scattering of hard X rays, nuclear reactions by bombardment, microwave antennas, microwave components and systems.

He has published over thirty journal articles and many technical reports on physics and microwave electronics subjects. He holds some fifteen patents, with others pending, primarily on microwave antennas and systems.

Dr. Van Atta is a Fellow of the American Physical Society and has been active in the Research Society of America and the International Scientific Radio Union, especially Commission VI. He has been very active in the IRE, having served as Chairman of the Antenna and Waveguide Technical Committee, the Professional Group on Antennas and Propagation, the Los Angeles Section, and the 1960 Winter Convention on Military Electronics, as well as Vice Chairman of the Professional Groups Committee. In addition he is a member of the American Association for the Advancement of Science, the American Association of Physics Teachers and the American Geophysical Union.

Scanning the Issue

The Interplay of Electronics and Vacuum Technology (Lafferty and Vanderslice, p. 1136)—The subject of vacuums usually brings to mind electron tube developments of the past. The performance of many of the early tubes was seriously limited by an inability to obtain a high vacuum. Subsequent improvements in vacuum techniques contributed greatly to the progress of the electron tube art. The subject is by no means one that belongs to the past, however. Gas ionization still plays a significant role in the operation of a number of modern electron devices. The advent of the space age has opened up other fields of interest. Ultra-high vacuums are now required to simulate on earth the conditions which electronic equipment will encounter in space. Special measuring instruments have been developed for rocket and satellite studies of the upper atmosphere and for hot-plasma experiments related to fusion. Particularly noteworthy is the important progress now being made in the fabrication of a wide variety of novel electronic components by vacuum deposited thin films, a process which requires a carefully controlled ultra-high vacuum. The excellent review and tutorial discussion of modern ultra-high vacuum techniques and systems presented here is most timely, not only because the subject is of great current importance in many areas of electronics but also because electronic components are playing a vital role in the development of modern vacuum technology.

New Concepts in Thermoelectric Device Design (Clingman, p. 1155)—A subtle brand of alchemy has arisen in the last decade by which materials may be tailored to a substantial degree to have certain desired properties. The proficiency with which this art is now practiced is having a revolutionary effect on electronics. Many new and improved materials are rapidly becoming available to the electronics engineer, not the least important of which are those which exhibit thermoelectric properties. As a consequence, thermoelectric devices are more than a reality; they are now becoming practical. Substantial numbers of engineers are becoming interested in methods of designing these devices. The operation of a thermoelectric device depends on a rather complex interrelationship between its thermal and electrical circuits. It is customary, therefore, to make simplifying assumptions in carrying forward the design analysis. The specific approach to be taken, however, usually depends on the device application and which of such factors as power, weight, efficiency, or cost is most important. The author has found that when efficiency or coefficient of performance is a major objective, an irreversible thermodynamic analysis of the system can be very useful. The result provides a valuable tool for preliminary analysis of a proposed design of a thermoelectric device.

IRE Standards on Piezoelectric Crystals: Measurements of Piezoelectric Ceramics, 1961 (p. 1161)—The key word in the foregoing title is "ceramics." While the IRE has issued three standards in the last decade dealing with piezoelectric crystals in general, none have dealt specifically with piezoelectric ceramics. This latter category covers a group of polycrystalline ferroelectric substances, of which ceramic barium titanate is a familiar example, which can be given lasting polar properties, including pyroelectric and piezoelectric effects, by subjecting them to high electric fields for a short time. These "poled" ferroelectric ceramics have become an increasingly important component in electromechanical devices along with piezoelectric crystals and magnetostrictive materials. The definitions, relations, and measurement methods developed in earlier IRE standards for piezoelectric crystals in general have now been adapted in this standard to ferroelectric ceramics.

The Field-Effect Tetrode (Stone, Jr., and Warner, Jr., p. 1170)—A new four-terminal semiconductor device has been developed which provides two current channels which are physically independent from each other but which electrically interact with one another. The device might be likened to a field-effect transistor in which the gate is replaced by a second channel so that each channel acts as a gate for the other. It is this mutual interaction between the two channels that gives the device its interesting properties. In addition to its possibilities as an amplifier, the field-effect tetrode has applications as a gyrator, isolator, and an electronically variable resistor. The development of this device marks a significant step forward in the realm of field-effect devices and will be of general interest to those concerned with microelectronics as well as particular interest to semiconductor device fabricators.

An Experimental Study of Bistatic Scattering from Some Small Absorber-Coated, Metal Shapes (Garbacz and Moffatt, p. 1184)—There is of course a great deal of interest today in the reflective properties of targets and the effect of coating them with absorbent materials. It is a subject that concerns investigators in several fields, including electromagnetic experimenters, radar designers, and electronic countermeasures engineers. The experimental results reported in this paper add significantly to the available data on the reflection or scattering from ideal geometrical objects, such as spheres, cylinders and cones, which are of a size to be resonant at X band. The results, presented in the form of an atlas of curves, show that coating these objects with an absorber will reduce the energy that is back-scattered but will increase the energy that is forward-scattered.

IRE Standards on Video Techniques: Definitions of Terms Relating to Television, 1961 (p. 1193)—This document brings up to date the IRE standard definitions of over two score terms common to the television field. Those who are interested in the standard definitions of terms in other fields as well are reminded that all IRE definitions published through 1959 are contained in the "IRE Dictionary of Electronics Terms and Symbols," which is available from IRE headquarters.

The Elimination of Intersymbol Interference by Input Signal Shaping (Gerst and Diamond, p. 1195)—Intersymbol interference can arise in a binary system because a pulse, upon passing through the system, generates a tail which may interfere with the following binary digit, especially if the latter is supposed to be a "zero." This type of interference can be eliminated by increasing the spacing between digits at a cost of slowing down the transmission rate. Another approach is to design the system to reduce the tail. This paper considers still another approach, namely, that of shaping the input signal to reduce the tail on the output pulse. In fact, it is shown that using a properly shaped continuous wave, instead of pulses, at the input can result in output pulses with no tail at all. The results will be of considerable interest to those engaged in computer and pulse communications systems. In addition, in solving the problem the author develops certain properties of Laplace transforms that should hold considerable appeal to network theorists.

The Interplay of Electronics and Vacuum Technology*

J. M. LAFFERTY†, FELLOW, IRE, AND T. A. VANDERSLICE†

Summary—Historically, vacuum technology has played an important part in the development of electron tubes. The operating characteristics of many early devices were dependent on the degree of vacuum obtained. The Roentgen X-ray tube and the Braun cathode-ray tube are examples of these. Improvement in vacuum technology made possible the development of many truly high-vacuum devices in which performance is independent of the inclosed gas pressure. Many modern electronic components no longer operate in a vacuum but are dependent on vacuum technology in their fabrication. These include microminiature circuit elements, cryotrons, photoconductor-electroluminescent devices and ferromagnetic memory systems—all dependent on vacuum evaporated films. Electronic components have also played an important part in the development of modern vacuum technology. These include thermistor gauges, electronic ionization gauges, ion pumps and electronic leak-detection equipment. This paper is devoted to a review of modern ultra-high vacuum systems and the electronic components used in them.

Introduction

HISTORICALLY, vacuum technology has played an important part in the development of electron tubes. The quality and life of these devices have been dependent on the ability to produce and maintain a high vacuum in them. In many of the early tubes, it was impossible to obtain a high vacuum. This led to the development of tubes which were, in many cases, dependent on some gas being present for their successful operation. The presence of gas in the tube placed a serious limitation on the voltage which could be applied without complete breakdown. An example of this is the cold-cathode X-ray tube. The characteristics of the early Roentgen "gas" X-ray tube depended markedly on the gas pressure in the tube. The electron stream in these tubes was produced by a low-pressure gas discharge. The current, applied voltage, and gas pressure were all interdependent. It was not uncommon in those days for a radiologist to use a series of tubes at different gas pressures to produce X rays of various energies or voltages. It was not until the highly evacuated Coolidge tube, with a hot tungsten filament to supply the electrons, was developed that the current could be adjusted independently of the applied voltage. The controllable features of the Coolidge tube have greatly facilitated research and engineering applications of X rays, particularly where precise control is required.

Another tube in which the degree of evacuation has played an important part in its performance is the cathode-ray tube. In the early Braun cathode-ray tube the electrons were liberated and concentrated by means of a gas discharge. The gas present in these early tubes was not dense enough to cause serious scattering of the electrons in the beam, but some of the gas molecules lying in the path of the beam were ionized and formed a positive ion core in the beam. The converging electric field produced by the positive core produced a definite concentrating action on the electron beam. The strength of this focusing action is dependent on the rate of ionization, which in turn depends upon the nature and pressure of the gas and the electron-beam voltage and density. Gas focusing cathode-ray tubes were by necessity slow-speed devices because of the long transit times for the ions. The attainment of a higher degree of vacuum in the cathode-ray tube made possible the development of the modern oxide-coated cathode electron gun by Zworykin in 1933. However, even today, the vacuum technology as practiced in modern cathode-ray television picture-tube processing has not progressed to the point where gas ionization effects are completely absent. Positive ions formed in the beam strike the cathode and limit its life by sputtering. This has been corrected to a large extent by the ion-trap gun. Before the aluminized backing was added to the television picture tube, difficulty was frequently encountered with ion-spot burn of the phosphor in the center of the face plate. This was caused by bombardment of the phosphor by high-velocity negative ions formed by electron attachment.

Electron-beam spread due to space charge is reduced in many modern microwave beam-type tubes by a positive ion core. In many devices this effect is enhanced by adding ion-trap electrodes at the ends of the beam to retain the ions and prevent their draining into the cathode or electron-accelerating region of the device.

Many of our modern electronic components no longer depend on a discharge in vacuum; nevertheless, vacuum technology plays an important part in their manufacture or processing. One of the most important processes is vacuum evaporation of materials for microminiature circuit elements. This involves the evaporation of thin films for passive circuit elements such as resistors and capacitors as well as superconducting films for cryotrons in logic and memory circuits. Vacuum evaporated ferromagnetic films are used in computer memory systems. Several electro-optical elements involving photoconductor-electroluminescent combinations are made by vacuum deposited films. Lack of reproducibility and uniformity in these devices are frequently associated with poor vacuum conditions. In order to maintain uniformity in some of these components which are particularly sensitive to impurities, it is necessary to carry out the evaporation process under ultra-high vacuum conditions at pressures of 10^{-10} mm Hg or better.

* Received by the IRE, February 2, 1961; revised manuscript received, April 17, 1961. The material presented in this paper has been abstracted principally from the revised edition of the late S. Dushman's book, "Scientific Foundations of Vacuum Technique" to be published by John Wiley and Sons, Inc.

† General Electric Research Lab., Schenectady, N. Y.

The testing of electronic components under conditions simulating free space will probably require pressures as low as 10^{-16} mm Hg.

It is interesting to note that, while vacuum technology has historically played an important part in the development of electronic components and will continue to do so in the future, electronic components are playing a role of increasing importance in the development of modern vacuum technology. The modern vacuum system uses semiconducting thermistor gauges for measuring relatively high pressures, electronic ionization gauges for measuring low pressures, and ion pumps for producing low pressures. Leaks are detected in vacuum systems and various other devices by electronic leak detectors using mass spectrometers, scintillation counters, Geiger-Müller tubes, and negative-ion detectors with their associated electronic circuitry.

This paper is devoted to a review of modern ultra-high vacuum systems and the electronic components used in them.

Low Pressure Manometers

Low gas pressures are measured by many different types of gauges. They may be classified, according to the basic principles involved, as follows: 1) Manometers which use mercury or some very nonvolatile liquid. The familiar U-tube manometer, and the well-known McLeod gauge are examples of these. 2) Mechanical manometers which depend on the measurement of the mechanical deformation suffered by a thin wall or diaphragm under pressure. Gauges of this type include the Bourdon spiral and aneroid barometer. 3) Viscosity manometers which depend on the viscous drag in a gas or involve the transfer of momentum by a gas. In the decrement type of viscosity gauge, a surface is set in oscillation and the rate of decrease of amplitude of oscillation is taken as a measure of the pressure. In the rotating disk or molecular gauge, a surface is set in continuous rotation and the amount of twist imparted to an adjacent surface is used to measure the pressure. The molecules striking the moving surface acquire a momentum in the direction of motion which they tend in turn to impart to the other surface. 4) Radiometer-type manometers, which depend on a mechanical force exerted between two surfaces maintained at different temperatures in a gas at low pressure. Instruments of this type are the Crookes radiometer and the Knudsen gauge. In these devices the molecules striking the hotter surface rebound with a higher average kinetic energy than those that strike the colder surface. Consequently, a momentum is imparted to the hot surface which tends to make it move. 5) Heat-conductivity-type manometers, which involve the effect of pressure on the rate of heat transfer. Gauges of this type are the thermocouple gauge, the Pirani resistance gauge and the thermistor gauge. These gauges all depend on the loss of heat from a surface by conduction through the gas at pressures where the distance between the hot and cold surfaces is less than the mean free path. 6) Ionization gauges which depend on the collection and measurement of ions formed by collisions between the gas molecules and high-velocity electrons or other energetic particles.

Fig. 1 shows the approximate operating range of pressure of the gauges just described. Major advances have been made in electronic methods of measuring pressure rather than in mechanical methods. The operating pressure range for ionization gauges has been extended in both directions from about 1 to 10^{-13} mm Hg. As low-pressure measurements have taken on more sophistication there has been a trend towards the use of partial-pressure gauges (mass spectrometers) for the identification of individual gaseous components. These mass spectrometers have taken on a variety of forms from the older magnetic-deflection types with secondary emission multipliers to increase the sensitivity and sweep rate to the more modern time-of-flight instruments and ion-resonance devices using RF fields and strong-focusing quadrupole lenses.

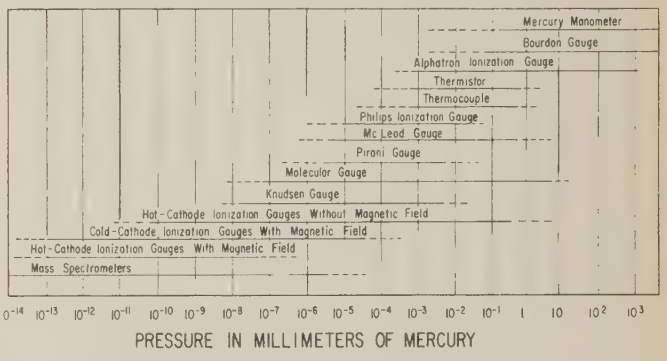


Fig. 1—Chart showing operating pressure ranges for different types of gauges.

Triode Gauges

The ionization gauge, in the form of a simple triode tube structure, is one of the oldest [1], [2] and still most widely used devices for measuring gas pressure under high-vacuum conditions. In this gauge, electrons from a thermionic cathode are accelerated through a positive grid structure. If the accelerating voltage is greater than the ionizing potential of the gas, there is a finite probability that the electrons will ionize the gas molecules on colliding with them. For a given geometry and constant grid voltage, the number of positive ions formed will be proportional to the gas pressure, provided the pressure is so low that any one electron does not make more than one ionizing collision during its flight. The number of positive ions produced is also proportional to the electron emission, provided space charge effects are negligible and do not alter the potential distribution in the gauge. A constant fraction of the ions produced is collected by an electrode which usually surrounds the grid and is negative with respect to the cathode. A measure of the resulting ion current gives an indication of the gas pressure. Let I_p denote the positive-ion current

to the ion collector, I_e the electron-emission current to the grid or anode, and P the gas pressure in the ionization gauge at some standard temperature. Then under the operating conditions discussed above

$$I_p = SI_eP \quad \text{or} \quad P = \frac{1}{S}\frac{I_p}{I_e}, \tag{1}$$

where the proportionality constant S is called the sensitivity of the gauge. If I_p and I_e are measured in the same units, S has the dimensions of reciprocal pressure. Obviously the sensitivity will depend on the nature of the gas present and the electrode geometry and voltages.

It is not uncommon for a triode ionization gauge, such as the VG-1A, shown in Fig. 2, for example, to have a sensitivity of $S = 20$/mm Hg for nitrogen. At a pressure of 10^{-6} mm Hg, substitution in (1) shows that only one ion is produced by every 50,000 electrons that travel from the cathode to the anode. The factors which affect the low-pressure limit of the triode gauge are discussed in the next section on gauges for ultra-high vacuums.

The upper pressure limit for most triode ionization gauges is about a micron. At higher pressures the ion current saturates, leveling off at a constant value independent of pressure. This is due to several effects. At high pressures the mean free path of the electrons between collisions with the gas molecules becomes comparable with the path length normally traveled by the electrons in going from the filament to the grid. Under these conditions the energy lost by the electrons in nonionizing inelastic collisions becomes important. The velocity of the electrons is reduced resulting in lower ionizing efficiencies during the latter part of their flight. The *effective* ionization potential [3] expressed in electron volts or average energy lost by the electrons per ionizing collision may well be equal to nearly half their initial kinetic energy of 150 ev.

The low-energy secondary electrons produced by ionizing collisions in a triode ionization gauge are, in most cases, not effective in producing further ionization. However, these electrons will be collected by the anode and measured with electrons emitted by the filament. If the total electron current to the grid is held constant during the operation of the gauge, as is often the case, the apparent gauge sensitivity will start to drop when these secondary electrons become comparable with the number of electrons emitted by the filament. It can be seen, by substituting numerical values in (1), that for the VG-1A with a sensitivity of $S = 20$/mm Hg, the ion current, and hence, the secondary electron current would just be equal to the electron-emission current at a pressure of 5×10^{-2} mm Hg, if the gauge could retain its sensitivity at this pressure. Actually, when the pressure becomes greater than a few microns, positive-ion space charge builds up around the cathode and an arc-like discharge is established. Under these conditions a characteristic glow may be observed in the gauge. The ion collector becomes a probe immersed in a plasma and collects the random ion current arriving at the sheath surrounding it. This current is no longer dependent on the pressure and cathode emission current in the usual way.

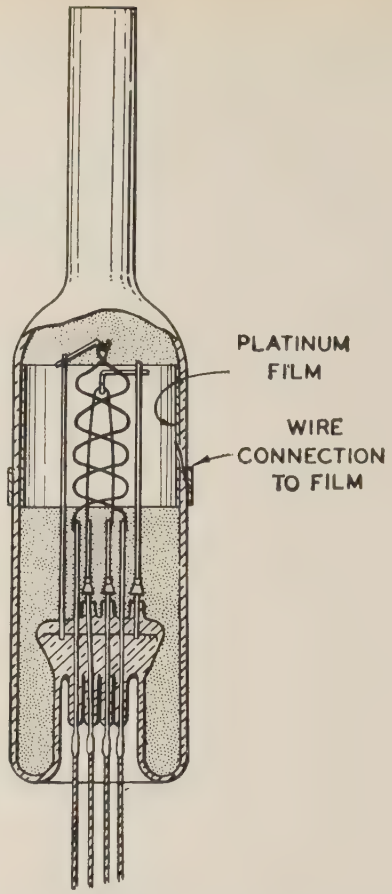


Fig. 2—The VG-1A triode ionization gauge. This popular high-vacuum gauge is outgassed by passing current through the grid and filament and by torching the envelope. The ion collector is a metallic film deposited on the wall of the envelope (Morse and Bowie).

Another factor that leads to nonlinearity in an ionization gauge at high pressures is a decrease in the ion collection efficiency. At high pressures the ions may be scattered to other electrodes before reaching the collector. This results in a smaller fraction of the total ions produced being collected by the ion collector.

Schulz and Phelps [4] have designed a high-pressure ionization gauge that takes these factors into account. Their gauge, the Westinghouse WX4145, shown in Fig. 3, operates in the approximate pressure range of 10^{-5} to 1 mm Hg. It has been used for measuring the pressure of chemically active gases as well as rare gases. The gauge consists of a 5-mil thoriated iridium filament located halfway between two parallel plates of molybdenum $\frac{3}{8} \times \frac{1}{2}$ inch spaced $\frac{1}{8}$ inch apart. The electrons emitted by the filament pass across the 60-mil gap directly to the anode plate without oscillatory motion.

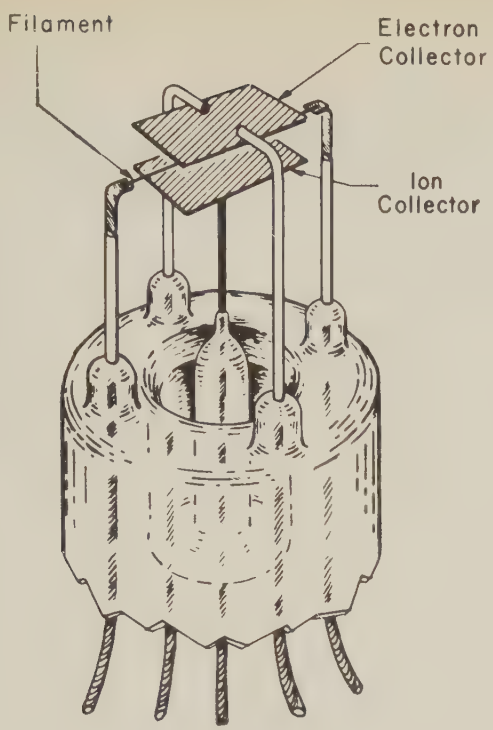


Fig. 3—High-pressure triode ionization gauge (Schulz and Phelps).

This gives the electrons a short path length independent of pressure with little chance of making more than one collision in passing from the filament to the anode. The short path length and the low anode voltage (60 v) give the gauge a sensitivity of only 0.6/mm Hg for nitrogen. This limits the secondary electrons produced by ionizing collisions to less than 10 per cent of the electron-emission current, even at pressures of 0.15 mm Hg. To insure efficient ion collection, the ion-collector electrode is made large compared to the filament, and its potential is adjusted to −60 v to assure parallel plane equipotential surfaces between the electrodes.

Philips Ionization Gauge

Many of the difficulties associated with chemically active gases reacting with the filament in the hot-cathode ionization gauges have been overcome by the Philips ionization manometer developed by Penning [5]. In this gauge, electrons are ejected from a cold cathode of zirconium, thorium, or other active surface by bombardment with positive ions which have been accelerated by passage through the cathode fall of potential. These secondary electrons are deflected by means of a magnetic field so that they travel in long helical paths before reaching the anode. The total length of path traveled by the electrons in going from the cathode to the anode is many hundreds of times the direct distance between the two electrodes. As a result, the ionization produced per electron at any given pressure is considerably greater than would be obtained in the absence of a magnetic field. The magnitude of the total discharge current, which is the sum of the positive-ion current to the cathode and the electron current from the same electrode, is used as a measure of the pressure of gas present.

Fig. 4 shows the construction of the gauge. The manometer tube M contains a ring-shaped anode R located between the cathode plates P. The magnetic field (about 370 oersteds) is applied by means of the permanent magnet H. A microammeter (to measure the current) and 1 megohm resistance are connected in series with the manometer across a dc source of about 2000 v.

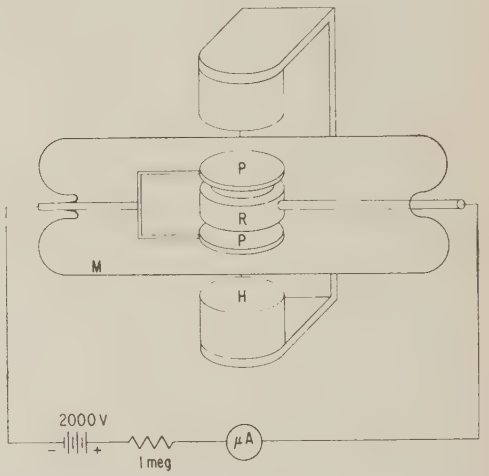


Fig. 4—Philips cold-cathode ionization gauge (Penning).

The Penning gauge does not have the accuracy of the hot-cathode triode gauge. Unstable oscillations generally occur in the glow discharge, and cause unpredictable jumps in the calibration curve. These discontinuities appear to be present in all gauges of this type, and may be as high as 10 per cent. In a later version of the gauge, Penning and Nienhauis [6] have improved the stability by replacing the ring anode with a cylinder.

Penning gauges operate over a pressure range of about 10^{-2} to 10^{-5} mm Hg. At lower pressures it becomes difficult to initiate the discharge, and in some cases it may fail completely to strike. The discharge in the Penning gauge removes gas from the sytem by processes that are discussed in a later section on ion pumps. This causes the gauge to act as a pump and disturbs the pressure distribution in the system. The rate at which gas is pumped by these cold-cathode discharge gauges is from 10 to 100 times greater than that of a hot-cathode triode gauge. For this reason they should be provided with a large tubulation with adequate conductance to prevent a pressure drop between the gauge and the vacuum system. Notwithstanding these disadvantages, the Penning gauge has found wide applications because of its simplicity and ruggedness.

Radioactive Ionization Gauges

A novel type of cold-cathode gauge was developed by Downing and Mellen [7] in the laboratories of the NRC Equipment Corporation of Newton, Mass.; it was designated the "Alphatron," to indicate that the ionization is produced by alpha particles. Fig. 5 shows a schematic diagram of the ionization chambers and electrical circuit. A dc potential of 108 v is applied between the ionization chambers and the ion collectors. The very small ionization current, produced by the alpha particles from the radium sources, is greatly amplified so that it can be read on a standard type of microammeter. The dc voltage, as well as the power for operating the amplifier, is obtained from the regular ac 60-cycle, 110-volt supply. The radium sources are so constructed that a small quantity of radium in equilibrium with its disintegration products, radon, radium A, radium B, and so forth, radiates alpha particles at a constant rate. Since radon, the first distintegration product of radium, is a gas, the source must be sealed in a plaque to prevent the loss of radon gas so that the succeeding products may be held in the source and their alpha activity utilized.

By using two ionization chambers, the Model 530 Alphatron gauge is made to operate with a linear response for air from 10^{-3} to 10^{3} mm Hg. The large chamber has a volume of 51 cc and with a radium source of 100 microcuries has a sensitivity for air of about 10^{-10} a/mm Hg. In the three high-pressure ranges from 10 to 1000 mm Hg the small ionization chamber is used in order to keep ionization current loss down due to volume recombination. The small chamber has a volume of 0.2 cc, and with a radium source of 1.5 microcuries has a sensitivity for air of about 1.5×10^{-13} a/mm Hg.

The sensitivity of the Alphatron depends on the kind of gas being measured. Conversion factors for the more common gases which are to be applied to the output current meter are given in Fig. 6. Due to recombination, the readings for gases heavier than air are not linear in the pressure range of 100 to 1000 mm Hg.

One obvious advantage of this gauge is that there is no filament to burn out and no possibility of chemical reaction between the gas and the cathode. It will also measure higher pressures than the triode ionization gauges. On the other hand, there are certain precautions (discussed very fully in the operating instructions) which have to be carefully attended to in using the gauge, in order to avoid any possible physiological effects arising from the radium emanation.

Spencer and Boggess [8] and their colleagues at the University of Michigan have also developed a radioactive ionization gauge using tritium for the radioactive source.

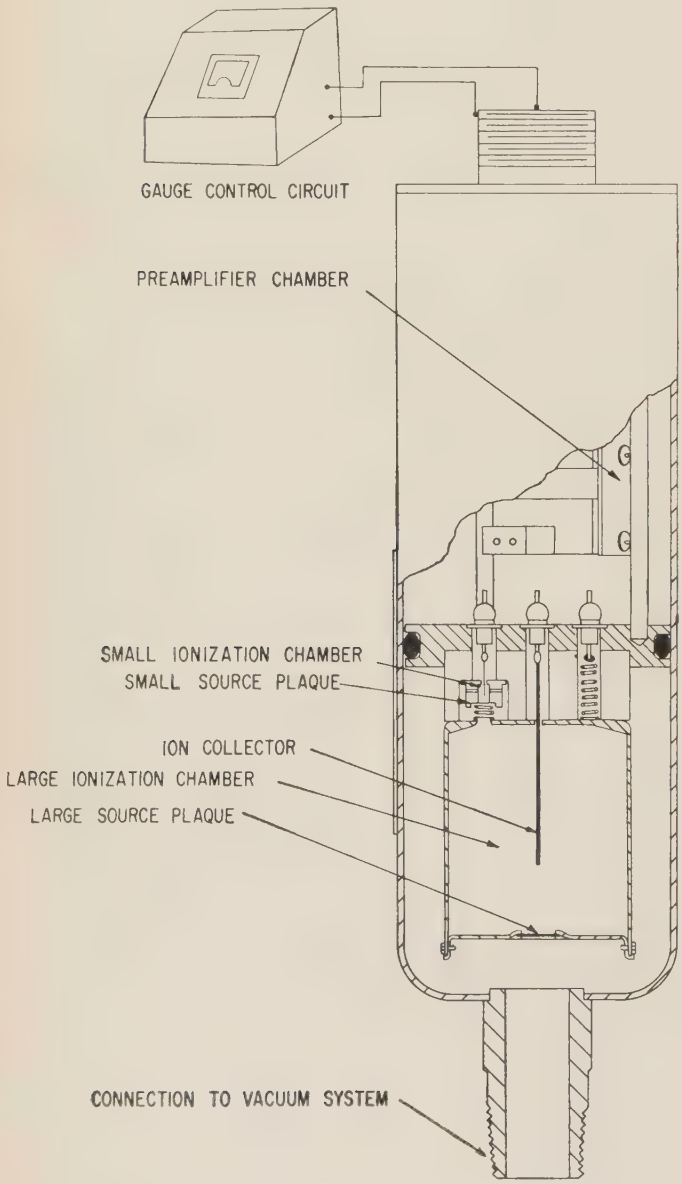


Fig. 5—Schematic sketch of the Alphatron ionization gauge which uses a radioactive source (Downing and Mellen).

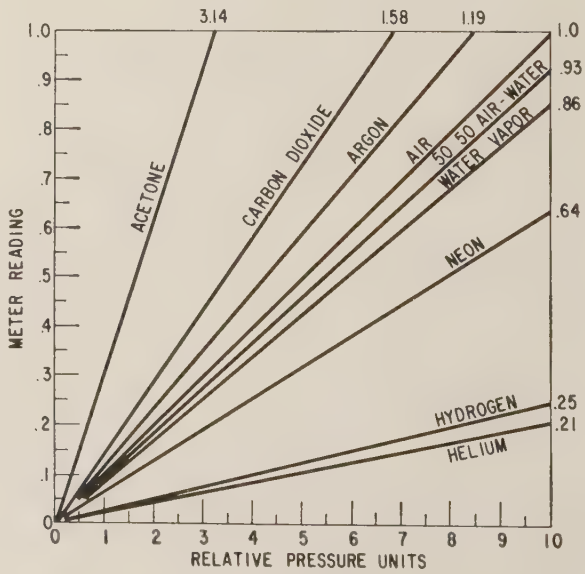


Fig. 6—Relative response of the Alphatron gauge to various gases.

Gauges for Ultra-High Vacuums

The conventional ionization gauge used prior to 1948 was not capable of measuring pressures below about 10^{-8} mm Hg. However, Nottingham and Apker had observed, in attempting to evacuate electronic devices to extremely low pressures, that thermionic and photoelectric emission characteristics indicated pressures much lower than 10^{-8} mm Hg. In 1947, Nottingham [9] presented evidence of a residual current to the ion collector which is completely independent of the pressure. This current is caused by photoelectrons ejected from the ion collector by soft X rays produced by 150-volt electrons striking the grid. Since the photoelectrons *emitted* from the ion collector cannot be distinguished on the current meter from the positive ions *incident* on the collector, there must exist a lower limit to the collector current, with decrease in pressure, which corresponds to pure photoelectric emission. For conventional gauges at normal operating voltages this X-ray photocurrent is about 2×10^{-7} times the anode current. Thus for a gauge with a sensitivity of $S=20$/mm Hg, the ion current to the collector would just be equal to the photoelectric current at a pressure of 10^{-8} mm Hg.

Bayard-Alpert Gauge

A consideration of these problems led Bayard and Alpert [10] in 1950 to develop the inverted ionization gauge shown in Fig. 7. The filament is placed outside the cylindrical grid, and the ion collector, consisting of a very fine wire, is suspended within the grid. The usual potentials are applied to the electrodes, +150 v on the grid and −45 v on the ion collector. Electrons from the filament are accelerated into the grid cylinder where they make ionizing collisions. A large fraction of the ions thus formed inside the grid are collected by the center wire. With this arrangement, the ion collector intercepts only a small fraction of the X rays produced at the grid. The small surface area of the collector wire presents a solid angle to the X rays from the grid that is several hundred times smaller than that for the conventional cylindrical collector.

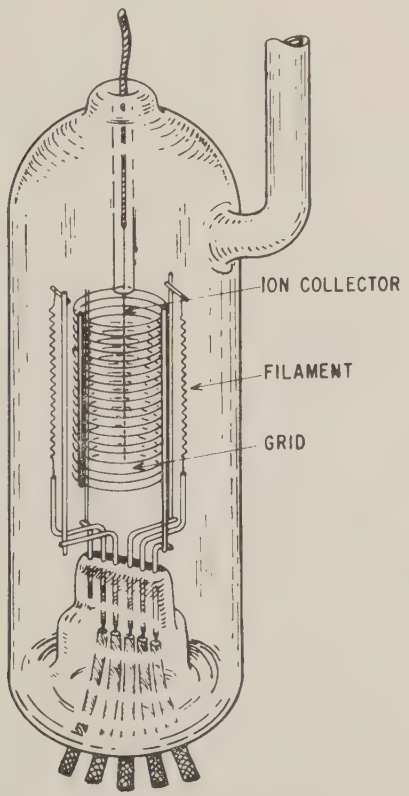


Fig. 7—The inverted triode ionization gauge (Bayard and Alpert).

A unique feature of the Bayard-Alpert gauge is the logarithmic potential distribution in the ionizing region between the cylindrical grid and coaxial ion collector. Since the potential inside the grid is nearly uniform, except in the immediate vicinity of the collector wire, the electrons travel within most of the grid volume with an efficient ionizing energy of nearly 150 ev. This is a distinct advantage over the conventional gauge, where the potential fall approximates a linear distribution between the grid and ion collector. In this case the electrons are decelerated to energies inefficient for ionization over a sizable portion of the volume between the grid and ion collector.

The almost uniform energy of the electrons in the ionizing space of the Bayard-Alpert gauge has allowed Nottingham to identify residual gases by measuring the appearance potential for ionization.

The second filament in the Bayard-Alpert gauge is electrically separated from the first, and not only serves as a spare, but may be used in connection with the flash-filament technique of estimating low gas pressure developed by Apker [11].

The glass sleeve around the ion collector lead prevents X rays from striking the large diameter lead-in wire, and provides a long leakage path between the collector and wall of the gauge which may become charged or electrically conducting from metallic deposits.

Nottingham [12] and Alpert [13] have suggested modifications of the Bayard-Alpert gauge to improve its sensitivity. The cylindrical grid is closed at top and bottom and a second grid, acting as a screen grid, is installed around all the electrodes. The purpose of closing the cylindrical grid is to prevent ions from escaping to the negatively-charged glass wall. At low pressures the ions may oscillate about the collector wire many times before being collected. Since the ions are likely to have velocity components parallel to the collector wire, they may escape through the ends of the grid before being collected unless the grid is closed. The screen grid shields the gauge from the wall charges. Operation of the screen grid at a negative potential causes the electrons to oscillate several times through the positive grid before being collected. This increases their average path length and gives the gauge a higher sensitivity. In some cases the screen grid is made by coating the glass envelope with a conducting film that is connected to an external lead. These improvements have increased the sensitivity by factors of two or three.

Nottingham [14] reported finding that at normal calibrating pressures the ion collector in the modified Bayard-Alpert gauge did not collect a constant fraction of the ions generated inside the grid. He found that for nitrogen at a pressure of 2.4×10^{-3} mm Hg the gauge may be in error by as much as a factor of 2 at emission currents of 100 μa and a factor of 6 at 1 ma. Correct readings are obtained at 10 μa and less. He observed similar effects to a smaller degree in the Bayard-Alpert gauge of type WL-5966. As the gas pressure is reduced the maximum permissible electron current increases inversely with the square root of the pressure. Nottingham suggests that this effect may be due to positive-ion space charge in the vicinity of the ion-collector wire.

The Bayard-Alpert gauge, in the form of the Westinghouse WL-5966, has a sensitivity of $S=12$/mm Hg for nitrogen and has a linear calibration curve over the pressure range of 10^{-9} to 10^{-4} mm Hg. The helium sensitivity is a factor of ten lower. Because of its simplicity of construction, ease of outgassing, and dual filaments, this gauge has found wide acceptance and use by workers in all phases of the high-vacuum field.

Cold-Cathode Inverted Magnetron Gauge

The Penning type of cold-cathode discharge gauge would appear to have certain advantages over the hot-cathode triode ionization gauges for measurement of ultra-high vacuums. There is no limitation on pressure measurements due to X-ray photoemission, since the number of electrons that strike the anode and produce the X rays decreases with the pressure. The vapor pressure of a hot tungsten filament also presents no limitations on the low-pressure limit. However, there are certain inherent disadvantages in the operation of a Penning gauge at pressures below 10^{-5} mm Hg. In most gauges the discharge fails to strike below these pressures. The application of higher voltages to start and maintain the discharge leads to field emission from the ion-collector electrode which cannot be distinguished from ion current by the external measuring circuit. This field-emission current establishes a lower-pressure limit for the operation of the Penning gauge analogous to the X-ray limit for the Bayard-Alpert gauge. To circumvent these difficulties Hobson and Redhead [15] designed an ionization gauge employing a cold-cathode discharge in crossed electric and magnetic fields. Their gauge, shown in Fig. 8, has the structure of an inverted magnetron with an auxiliary cathode. This geometry provides efficient electron trapping in the discharge region, and the auxiliary cathode provides the initial field emission for starting and allows the positive-ion current to be measured independently of the field-emission current. The auxiliary cathode also acts as an electrostatic shield for the ion collector. The two short tubular shields, which project 2 mm into the ion collector from the auxiliary cathode, protect the end plates of the ion collector from the high electric fields and provide the field emission which initiates the discharge.

The gauge operates with an applied magnetic field of 2060 oersteds and a potential of six kv on the anode. Under these conditions the relationship between ion collector current and pressure is given by

$$i_p = cP^n, \tag{2}$$

where i_p is the collector current in amperes, P is the pressure in mm Hg, c is a constant between 1 and 10, and n lies between 1.10 and 1.4 for various gauges. According to Hobson and Redhead, the value of n is essentially independent of the anode voltage, and approaches unity as the magnetic field is increased. The dimensions of the gauge have little effect on the value of n. In the theory of the Townsend discharge applied to the inverted magnetron gauge, Redhead [16] has pointed out that this nonlinear relationship between the ion current and pressure exists because the striking voltage is a slowly varying function of the pressure.

Unlike the triode gauges, the sensitivity ratio of the inverted magnetron gauge for various gases is a function of pressure. The sensitivity ratio for helium to air decreases with pressure and is also a function of the anode voltage.

Oscillations were observed in the inverted magnetron gauge under most operating conditions. Discontinuous jumps in the mode of oscillation from one frequency to another give only small discontinuities in the current-pressure characteristics.

The time lag between the application of anode voltage to the gauge and the initiation of the discharge becomes

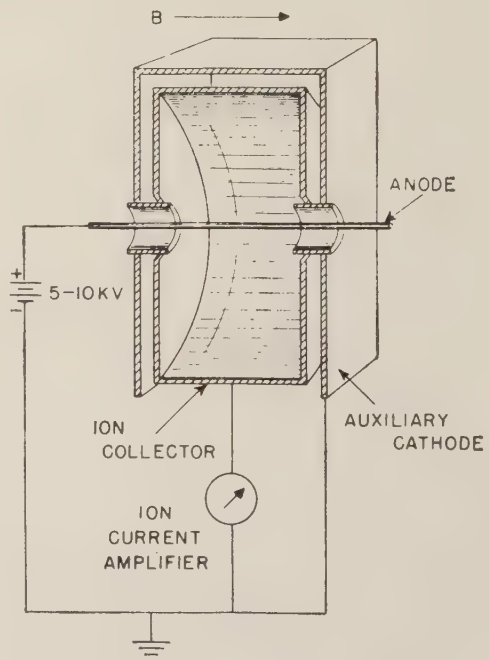


Fig. 8—The cold-cathode inverted magnetron ionization gauge (Hobson and Redhead).

appreciable and variable at pressures below 10^{-8} mm Hg. At pressures near 10^{-12} mm Hg the time lag was as long as ten minutes; however, it is reported that no gauges failed to strike.

A commercial version of this gauge, type 2205-02, is now manufactured by the NRC Equipment Corporation of Newton, Mass. The commercial gauge operates over a pressure range from 10^{-4} to 10^{-12} mm Hg with a sensitivity of 4.5 a/mm Hg for air at 6000 v with a magnetic field strength of 1000 oersteds.

Hot-Cathode Magnetron Ionization Gauge

In order to extend the low-pressure limit of the conventional hot-cathode ionization gauge it is necessary, at a given emission current, to increase the ratio of the ion current to the X-ray photocurrent. As previously explained, this was accomplished in the Bayard-Alpert gauge by reducing the X-ray photocurrent without substantial loss of gauge sensitivity. This ratio may also be increased by increasing the sensitivity of the ionization gauge. It is evident that if the gauge is modified in such a way that the electrons travel in longer paths before they are collected by the positive grid or anode, the probability of their colliding with and ionizing a gas molecule will be greatly enhanced and the sensitivity of the gauge will be improved with no increase in X-ray photoemission. Lafferty [17] has applied this principle in developing a hot-cathode magnetron ionization gauge for ultra-high vacuum use. In this arrangement, shown in Fig. 9, a cylindrical magnetron is operated with a magnetic field greater than cutoff. Two end plates maintained at a negative potential relative to the cathode prevent the escape of electrons. One or both of these plates may be used to collect the positive-ion current generated in the magnetron. Electrons emitted by the tungsten-filament spiral around the axial magnetic field in the region between the negative end plates. If the magnetic field is sufficiently high, most of the electrons fail to reach the anode. Some of the electrons make many orbits around the cathode before being collected. The electron density is therefore increased by the presence of the magnetic field and the probability of ionizing the gas is considerably increased. This is illustrated in Fig. 10, where the ion current to one end plate and the electron current to the anode are plotted as a function of magnetic field for a magnetron gauge with an anode

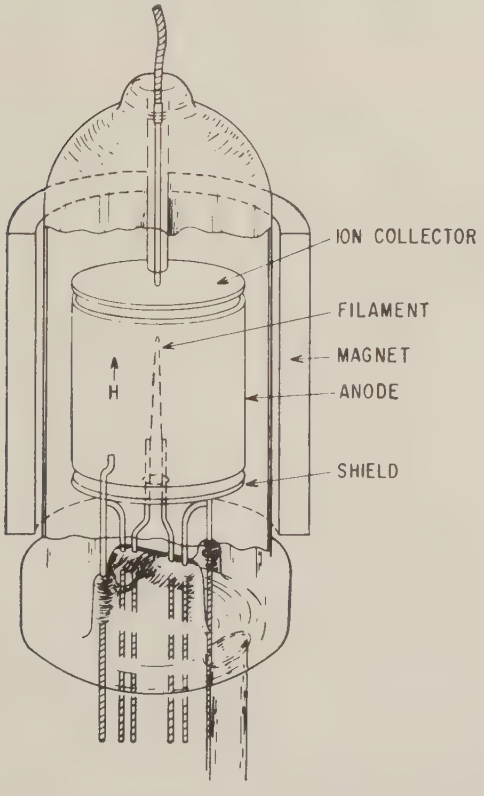


Fig. 9—The hot-cathode magnetron ionization gauge (Lafferty).

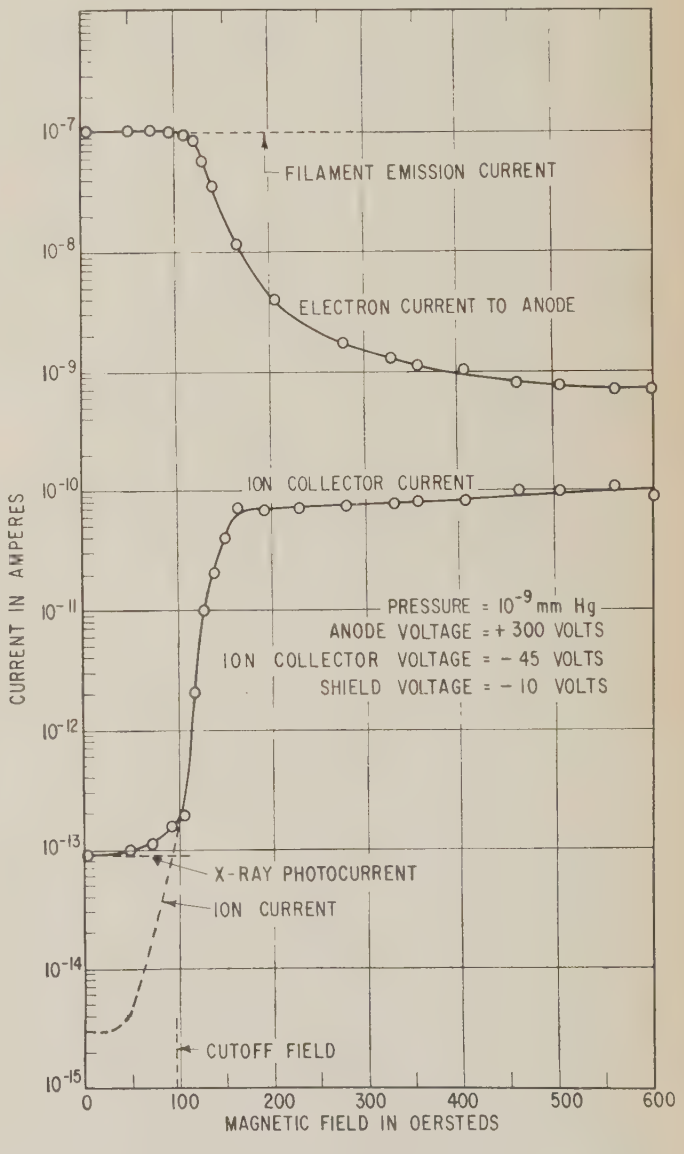


Fig. 10—Ion-collector current and anode electron current as a function of magnetic field for the hot-cathode magnetron gauge.

15/16 inch in diameter and $1\frac{1}{8}$ inches long. The 8-mil hairpin tungsten filament is $\frac{3}{4}$ inch long, separated 40 mils at the base. The filament temperature is adjusted to give an emission current of 10^{-7} a with zero magnetic field. Under these conditions the ion-collector current is nearly 10^{-13} a at a pressure of 10^{-9} mm Hg. However, from measurements made in the 10^{-6} mm Hg pressure range, the sensitivity of the gauge is known to be 30/mm Hg. Thus the true ion current at a pressure of 10^{-9} mm Hg would be only 3×10^{-15} a, as shown by the dotted line in Fig. 10. The actual current measured in the ion-collector circuit is 30 times this value and is essentially all photocurrent produced by X rays from the 300-volt electrons striking the anode. From this it would appear that on the average one photoelectron is emitted by the ion collector for every million electrons striking the anode. As the magnetic field is increased and the electrons begin to miss the anode, their path length is increased. This is indicated by a sharp rise in the ion current and a drop in the electron current collected by the anode. At a magnetic field strength of 250 oersteds, the ion current is enhanced 25,000 times over what it would be without the field, and the electron current collected drops to 1/50 of its former value. The ratio of ion current to X-ray photocurrent is thus increased 1.25×10^{6} times by application of the magnetic field. Since the cut-off current to the anode remains constant independent of pressure at these low pressures, the ion current to the collector would just equal the X-ray photocurrent at a pressure of 2.4×10^{-14} mm Hg. Thus, pressures at least this low could be measured. In practice, the ability to read low pressure is limited by the sensitivity of the external circuit used to measure the ion current.

Hot-cathode magnetron gauges have been shown to have extremely high sensitivities when operated in the ma electron-emission range at pressures of the order of 10^{-5} mm Hg [18]. However, they have always been subject to excessive pumping action and unstable operation frequently associated with oscillations. Lafferty has found that these conditions may be avoided by operating the magnetron gauge at very low electron-emission levels.

Partial-Pressure Gauges

While the ionization gauges give a measure of the total residual pressure of the gases in a vacuum system, there are times when it would be highly desirable to know what these residual gases are. In the hot-plasma experiments related to fusion, it is important to know the purity of the gases involved since the presence of ions of large mass compared to the hydrogen isotopes tend to cool the plasma. Recent interest in determining the neutral and ionic components of the upper atmosphere and beyond has stimulated the design of special equipment for this purpose. Successful rocket and satellite flights have already been made with the Bennett radio-frequency type of mass spectrometer. Many more such devices are sure to follow for space investigations.

Omegatron

The omegatron, originally developed by Sommer, Thomas, and Hipple [19] for measuring atomic constants, has been used by Alpert and Buritz [20] as a mass spectrometer for measuring the partial pressures of the various gases in an ultra-high vacuum system. A simplified version of the omegatron capable of high-temperature outgassing as developed by Alpert and Buritz is shown in Fig. 11.

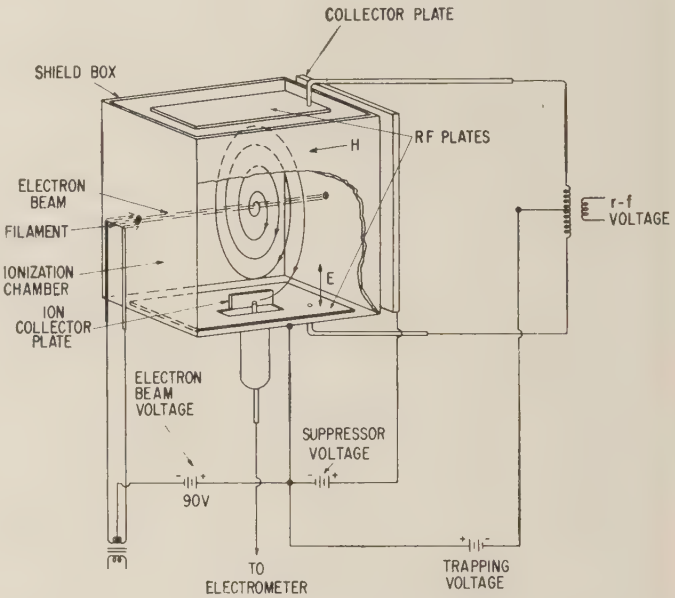


Fig. 11—Schematic diagram of a simplified version of the omegatron (Sommer, Thomas, and Hipple) developed by Alpert and Buritz.

The operation of the omegatron is similar to that of the cyclotron. Electrons emitted from the hot filament are accelerated through a 1/16-inch-diameter aperture to form a 4-μa beam at 90 v. This beam, which produces ions in the ionization chamber, emerges through a second aperture and is collected by a collector plate biased positively with respect to the shield to suppress secondary emission. The parallel magnetic field H has a strong collimating action on the electron beam. The shield box forms a 2-cm cube. The RF plates, which form the top and bottom of the ionization chamber, are connected to a source of RF voltage (about one or two volts). These plates produce an RF field E across the ionization chamber perpendicular to the magnetic field. Ions formed by electrons colliding with the gas molecules within the electron beam are caused to spiral around the magnetic lines of force by their own thermal and dissociation energies. The radii of these spirals are very small and few ions would normally escape from the electron beam due to their own initial energy. However, the applied weak electric RF field causes the ions to be accelerated in Archimedes-like spiral orbits of increasing size provided the frequency of the applied RF voltage is the same as the cyclotron frequency of the ions. A trapping voltage that is positive with respect to the RF

plates is applied to the shield box to produce an electric field which retards the loss of ions in the axial direction of the magnetic field. This gives the RF field an opportunity to act on the ions over a greater number of cycles. The spiral orbits terminate on a 1/16-inch-square ion-collector plate. The ion current to this electrode, detected by a vibrating-reed electrometer, is a measure of the abundance of the gas with a cyclotron frequency equal to applied frequency.

Alpert and Buritz report that an omegatron of this design has a sensitivity of $S = 10/\text{mm Hg}$ which is comparable to that of an ionization gauge. With a magnetic field intensity of 2100 oersteds the RF oscillator must be swept from 3.2 Mc to 81 kc to cover a mass range from 1 to 40. There is some discrepancy between the observed and calculated frequency for a given mass, presumably due to lack of uniformity of the RF field. However, the instrument has adequate resolution up to at least mass 40.

An analysis of the ion motion in the omegatron has been made by Sommer, Thomas, and Hipple [21] assuming a uniform sinusoidal varying RF field normal to a constant magnetic field. The results of their study may be summarized as follows:

Cyclotron or resonant frequency:

$$f = 1.54 \frac{H}{M} \text{ kc.}$$

Number of revolutions made by ions before reaching collector at resonance:

$$n = 3.06 \cdot 10^{-5} \frac{R_0 H^2}{E_0 M} .$$

Time for ions to reach collector at resonance:

$$t = 0.02 \frac{R_0 H}{E_0} \ \mu\text{sec.}$$

Length of spiral path for ions at resonance:

$$L = 9.6 \cdot 10^{-5} \frac{R_0^2 H^2}{E_0 M} \text{ cm.}$$

Final energy of resonant ions at collector:

$$V = 4.8 \cdot 10^{-5} \frac{R_0^2 H^2}{M} \text{ ev.}$$

Maximum radius attained by nonresonant ions differing in mass by the amount ΔM from the resonant ions of mass M:

$$r_m = \frac{2}{\pi n} \frac{M}{\Delta M} R_0 \text{ cm.}$$

Resolution (defined as midpeak frequency per width of resonant peak, theory assumes parallel-sided peaks):

$$\frac{M}{\Delta M} = 4.8 \cdot 10^{-5} \frac{R_0 H^2}{E_0 M} ,$$

where

E_0 = peak value of sinusoidal RF field in v/cm,
M = mass of ion in atomic mass units,
R_0 = distance from electron beam to ion collector in cm, and
H = magnetic field intensity in oersteds.

If these equations are applied to the Alpert and Buritz omegatron it is found that if one assumes $E_0 = 1$ v/cm, $R_0 = 1$ cm and $H = 2100$ oersteds, then for helium the required radio frequency for resonance is 810 kc. At resonance the helium ions will spiral around 34 times traveling about one meter in 42 μsec before being collected. The helium ions will gain 53 ev of energy from the RF field. At the resonance frequency for helium, the molecular ions of hydrogen travel less than 0.4 mm away from the electron beam. The resolution is nearly 53.

The resolution of an omegatron may be improved by operating at low RF voltages. However, under these conditions the ion-path length becomes large and the device must be operated at low pressures to prevent scattering. Further effects of varying the operating parameters on the performance of the omegatron are discussed by Edwards [22].

Magnetic-Deflection Mass Spectrometers

Mass spectrometers of the magnetic-deflection type have also been used in measuring the residual gases in ultra-high vacuum systems. Reynolds [23] has described a high-sensitivity mass spectrometer for noble gas analysis. A nine-stage electron multiplier with magnesium-silver dynodes is used to give a gain in the range of 10^3 to 10^6 electrons per ion. This increase in sensitivity permitted Reynolds to measure partial gas pressures of the order of 10^{-12} mm Hg. A total pressure of 5×10^{-10} mm Hg was achieved during operation of the spectrometer after rigorous bakeouts.

A small, portable, magnetic-deflection-type mass spectrometer with a secondary emission electron multiplier has also been developed by Davis and Vanderslice [24] for studying residual gases at ultra-high vacuums and for making transient pressure studies. This device is shown in Fig. 12. Because of its small size, it has the advantage that it can be sealed directly to the tube or system being investigated and is easily transportable. The spectrometer may be baked out at 450°C and operated at ultra-high vacuums when properly processed.

The design consists of a 90° sector-5-cm radius of curvature magnetic analyzer which will resolve adjacent mass peaks up to about mass 140. A Nier-type ion source is used and the ion detector is a ten-stage DuMont 6467 electrostatically focused electron multiplier

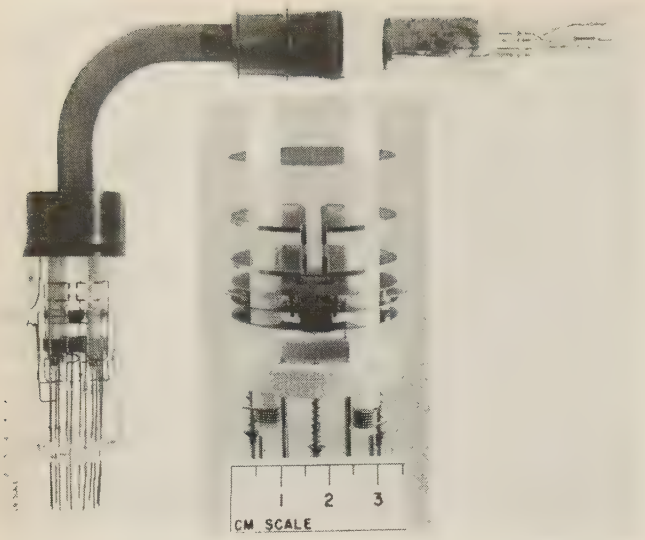


Fig. 12—A small portable mass spectrometer with secondary emission multiplier for the study of transient pressure phenomena at ultra-high vacuums (Davis and Vanderslice).

with a gain of one to ten million. The sensitivity of this spectrometer is in the range of 0.02 to 0.2/mm Hg without the multiplier. Assuming that the lowest current which can be conveniently measured is 10^{-14} a, this spectrometer, without the multiplier, could be used to detect partial pressures of about 10^{-10} mm Hg. With the multiplier, the output current is increased by a factor of 10^6 to 10^7, but because of the multiplier dark current, a gain in sensitivity of only 10^3 can be realized at room temperature. Under normal conditions a dark current of 10^{-10} a was obtained. With a multiplier gain of 10^7 this corresponds to an equivalent ion current of 10^{-17} a. This is equal to the signal current that would be produced by a partial pressure of 10^{-13} mm Hg. Cooling the multiplier in liquid nitrogen or counting individual ion pulses reduces the dark current by a factor of 100, making pressures of the order of 10^{-15} mm Hg measurable.

An additional advantage of the multiplier is that it raises the signal level to a point where a low output load resistance may be used to give a short response time. This makes it possible to scan the mass range and display the spectrum on an oscilloscope. Several ion species may thus be observed almost simultaneously during a transient pressure or composition phenomenon. The saw-tooth voltage which is available on a Tektronix 545 scope and automatically synchronized with the display makes an excellent source of sweep voltage. Fig. 13 shows an example of an oscilloscope display for the isotope spectrum of CO^+ obtained after bakeout at a pressure of 6×10^{-8} mm Hg. The mass peaks 28, 29, and 30 correspond to $C_{12}O_{16}^+$, $C_{13}O_{16}^+$, and $C_{12}O_{18}^+$ respectively. These peaks occur in the ratio 100:1:0.2. This spectrum was taken at a sweep speed of 3 msec per unit mass. Sweep rates as high as 1.5 μsec per unit mass have been used successfully. At the higher sweep rates the familiar well-defined mass peaks degenerate into groupings of pulses due to the collection of individual ions.

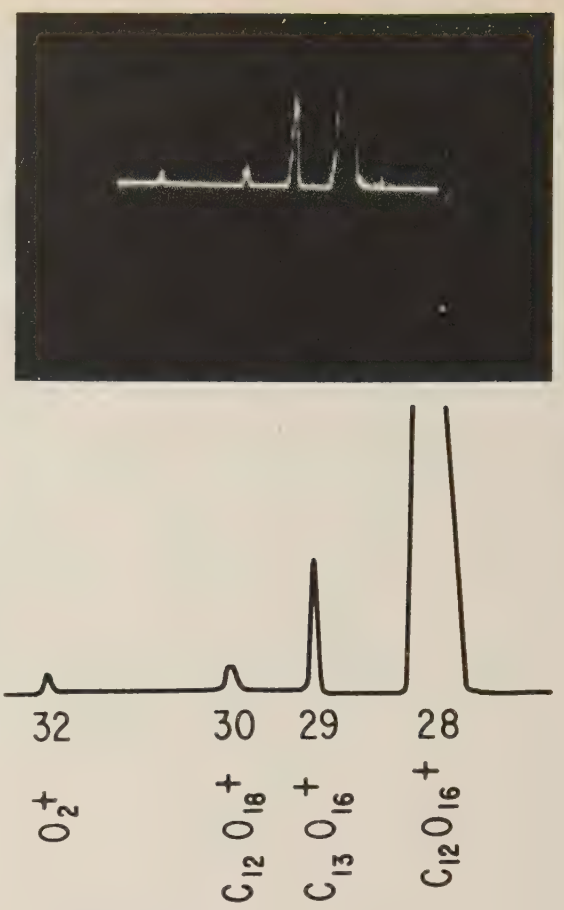


Fig. 13—Oscillogram of CO^+ isotopes taken at 6×10^{-8} mm Hg with a sweep speed of 3 msec/unit mass with the spectrometer shown in Fig. 12.

Vacuum Systems

For any operating vacuum system there will be established a stationary pressure P_e, which corresponds to the equilibrium between the flux of gas into the system and rate of exhaust. This rate of flow of gas Q into the system may arise from desorption from the walls of the system, back diffusion from the pumps, or atmospheric gas permeation of the walls. For a system of volume V and pumping speed S, the rate of reduction of pressure is given by

$$\frac{dP}{dt} = -\frac{S}{V}P + \frac{Q}{V}. \tag{3}$$

For the simple case in which S and Q are constants, independent of pressure, the solution of this equation is

$$P = \frac{Q}{S} + \left(P_0 - \frac{Q}{S}\right)e^{-t/(V/S)}, \tag{4}$$

where V/S is now the pumping-time constant or characteristic pumping time of the system, *i.e.*, the time required to pump the system down to 0.368 of its initial pressure P_0. The equilibrium pressure finally attained in the system will be

$$P_e = \frac{Q}{S}. \tag{5}$$

Obviously, then, to achieve ultra-high vacuum it is necessary that the rate of gas leakage into the system divided by the pumping speed of the system be small.

In order to keep the influx of gas low, it is necessary to keep back diffusion from pumps at a minimum by using effective traps with low-backstreaming pumps.

Desorption from walls of the system is a major source of gas, and this is generally decreased by baking the system to temperatures up to 500°C or by immersing the system in a refrigerant such as liquid helium [25]. The required high-temperature bakeout makes the use of stopcocks, glass taper fittings, wax, etc., impractical.

The leak rate of gas through the walls of the system must be small. Alpert and Buritz [26] have shown that the ultimate limit to the achievement of very low pressures in glass systems is fixed by the diffusion of atmospheric helium through the walls of the system. They measured this rate for borosilicate glass as approximately 10^{-15} mm l/sec/cm^2. A one-liter system with a surface area of 1000 cm^2 would require a pumping speed of only 0.01 l/sec to maintain a pressure of 10^{-10} mm Hg. Norton [27] has made measurements of the permeation rate of helium through various glasses and the results are shown in Fig. 14. The rate for borosilicate glass is in substantial agreement with the value given by Alpert and Buritz.

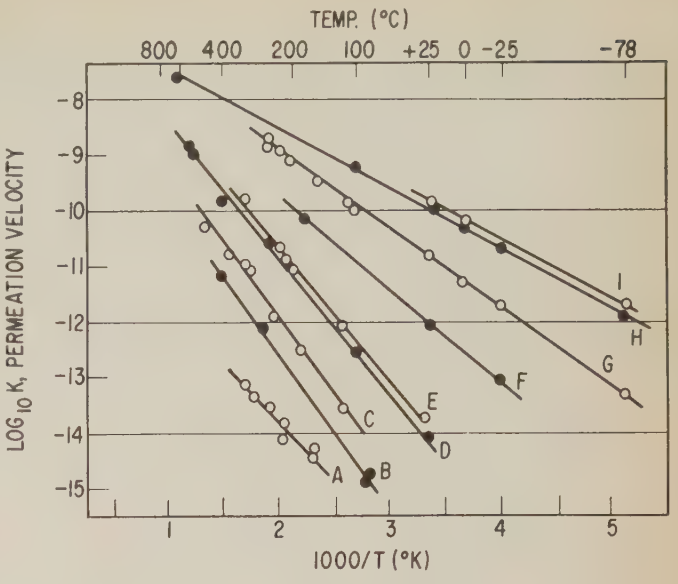


Fig. 14—The log of the permeation velocity K of helium plotted against the reciprocal of the absolute temperature T for various glasses. K is in units of cm^3 gas (NTP/sec/cm^2 area/mm thickness/cm Hg gas-pressure difference). Curve A) Lead borate glass. B) X-ray shield glass. C) Combustion tubing Corning No. 1720. D) Soda-lime glass Corning No. 0080. E) Phosphate glass. F) Borosilicate glass Kimball No. 650. G) Chemical Pyrex-brand glass No. 7740. H) Fused silica. I) Vycor-brand glass.

As the graph shows, the permeation of atmospheric helium can be decreased by a selection of the glass used in the vacuum system. Corning 1720, for example, has a permeation rate 10^{-5} lower than ordinary borosilicate glass (Corning 7740). Since the diffusion rate of helium is much lower through crystalline materials than through glass, it is expected that an all ceramic-metal system would have a low permeation rate for helium and that the ultimate pressure would only be limited by the outgassing of the metal and ceramic.

Another limit to the achievement of low pressures is the finite vapor pressure of the tungsten filament in the ionization gauge. At 2300°K, for example [28], the vapor pressure is 10^{-12} mm Hg. This limits the temperature to which a tungsten filament may be heated in an ultra-high vacuum ionization gauge. However, lanthanum boride [29] produces 10 ma emission at 1000°K and the vapor pressure is about 10^{-4} lower than tungsten at the same electron-emission current density.

In the past few years, a variety of components specifically designed for ultra-high vacuum systems have become available. A discussion of these follows.

Pumps for Ultra-High Vacuum

Diffusion Pumps

The operation of a diffusion pump depends on the effusion of gas molecules from the region being evacuated into the directed vapor stream of the pump [30]. Some of the directed momentum of the vapor molecules is imparted to the gas molecules in the system thus creating a pressure gradient causing the gas to flow through the pump. This process is independent of pressure once the pressure had been lowered by a backing pump to a value at which molecular flow or effusion can occur and the pumping speed will rise to a plateau value and remain there for all lower pressures. The rate of gas evolution from the pump itself becomes significant at lower pressures and eventually exceeds the measured rate of introduction of gases into the pump from the vacuum system. Eventually, then, the net pumping speed of the diffusion pump falls to zero due to the gas evolution and backstreaming of the pump fluid from the pump itself.

Hagstrum [31] and Becker and Hartman [32] at the Bell Telephone Laboratories have used mercury-diffusion pumps with liquid-nitrogen-cooled traps to attain ultra-high vacuum. Recent experiments by Venema and Bandringa [33] have demonstrated that a properly designed mercury pump and a series of traps will attain a vacuum of at least 10^{-12} mm Hg. Vanderslice has achieved a pressure of 3×10^{-12} mm Hg at room temperature using the techniques of the above authors.

Oil diffusion pumps have very high pumping speeds, but until recently it was felt that their pressure limit was in the vicinity of 10^{-7} mm Hg. Even with a high pumping speed, the ultimate pressure is limited by the high value of backstreaming. Alpert [34] has shown that at some pressure between 10^{-7} and 10^{-8} mm Hg the conventional oil diffusion pump becomes a source of contamination for a "clean" vacuum system. The oil pumps were at first used to evacuate the systems down to 10^{-7} mm Hg and after the system was closed off from the oil pumps, the pumping action of the ionization gauge was

used to pump to lower pressures. Alpert [35] subsequently designed a copper-foil trap, shown in Fig. 15, that would prevent the backstreaming of oil vapor but would not seriously restrict the conductance and pumping speed of the system. With the gettering action of the copper-eliminating backstreaming, the oil pump evacuated the system to pressures below 10^{-10} mm Hg. The copper-foil trap was effective even at room temperature and for periods of several months. The trap was reactivated by baking with the rest of the system. The exact mechanism whereby the trap adsorbs backstreaming oil vapor at room temperature is not fully understood, but with proper traps an oil diffusion pump may be used in ultra-high vacuum experiments.

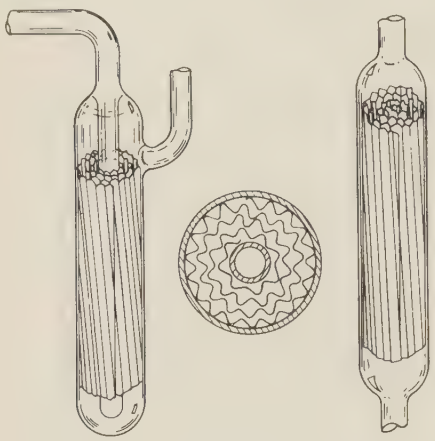


Fig. 15—Copper-foil trap (Alpert).

The recent work of Biondi [36] utilizing nonrefrigerated molecular sieve traps has had, and will continue to have, a profound impact on the use of oil pumps for ultra-high vacuum experiments. With these traps it is now possible to achieve ultra-high vacuum with oil pumps without the use of refrigerants for reasonably long times. The most popular materials at the moment are zeolite and alumina with some advantages being claimed for alumina. Harris [37] has demonstrated that the activity of oxide cathodes may be maintained for a period of several days, and perhaps longer with the use of alumina traps. A comparative test without alumina and with conventional cold trapping showed that a similar oxide cathode lost much of its activity in a comparable time.

Ion Pumps

The ionization gauge itself may be used for pumping, once the pressure has been brought to a low value. The pumping speed of ionization gauges is low, of the order of hundredths of liters per second, but with a low influx of gas Q the speed is sufficient for a well-baked-out system. Alpert [38] has demonstrated that a Bayard-Alpert gauge with titanium continually evaporated to the wall has a pumping speed of at least 20 liters/sec at low pressures.

The most important development in the last few years has been the advent of commercially available ion pumps with relatively high pumping speeds down to at least 10^{-9} mm Hg. Hall [39] reports a pressure of 10^{-11} mm Hg using a baked-metal system and an ion pump.

The cold-cathode ion pump is basically a variation of a Penning ionization gauge consisting of a ring anode and two cathode plates in a magnetic field as shown in Fig. 4. The anode is operated at high-positive potential with respect to the cathode. Electrons emitted by the cold cathode are forced into a spiral path by the presence of a strong magnetic field. The increased electron path results in a high probability for collision and ionization between electrons and gas molecules. The positive ions then bombard the cathode and sputter metal from the cathode. The sputtered metal deposits in various regions of the tube forming stable compounds with the chemically active gas molecules. Chemically inert gas atoms such as argon are also pumped, but by a different mechanism. In an ion pump much of the inert gas is initially found in the sputtered deposit on the cathode. Fig. 16 shows a radiograph of the cathode of a commercial two-electrode pump in which radioactive krypton 85 has been pumped. The pump was disassembled and the cathode placed in contact with a photographic film showing that the krypton was chiefly located in the sputtered deposit on the cathode.

If the ion current density on an electrode surface is uniform, the clean-up of inert gas on that surface is zero after a short period of time. Initially a small number of ions will be imbedded in the surface, but as soon as sputtering occurs, imbedded gas is released. A condition is soon reached in which the net clean-up rate is zero since the rate at which ions are driven into the newly exposed surface is just equal to the rate of release of gas from the surface by sputtering. If an ion current density gradient exists on the electrode surface, there will be a build-up of sputtered metal in areas of low current density and consequently gas clean-up will occur. The Penning-type discharge in a two-electrode pump is somewhat unstable during operation, producing changes in the distribution of the ion current density at the cathode surface. This results in the resputtering of previously sputtered metal on the cathode, and consequently in the release of gas previously cleaned up. This is frequently referred to as the ion pump memory effect. This effect is reported to be minimized by grooving the cathode [40].

Inert gases are also cleaned up at the anode to some extent [40], [41]. The gas is found in the metal which has been sputtered from the cathode. There is the question how the gas sticks to the anode since unexcited inert gas atoms are not adsorbed on the electrode surfaces for long enough times at room temperature to be covered by sputtered metal and the ions normally do not have sufficient kinetic energy to reach the anode. There are several plausible explanations for this: 1) neutral inert gas atoms are excited by the discharge stick

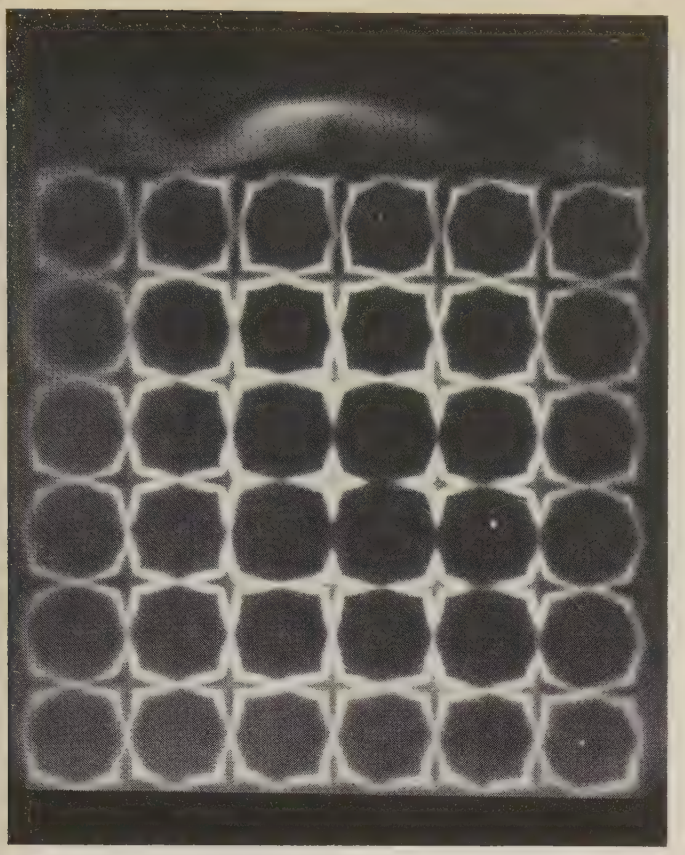


Fig. 16—Radiograph showing the location of radioactive krypton 85 in the sputtered deposit on the cathode of an ion pump.

to the anode and are covered by sputtered metal from the cathode; 2) high-velocity neutral atoms produced by charge exchange are driven into the anode and then covered by sputtered metal from the cathode; 3) the gas ions gain sufficient kinetic energy to reach the anode through oscillations in the discharge; and 4) the gas is swept out of the space between the electrodes by the high flux of the metal vapor. The first two explanations appear more likely. Although the anode mechanism is less efficient than coverage of ions at the cathode, the clean-up is permanent because resputtering of material from the anode cannot occur.

Three-electrode ion pumps have been studied in this laboratory [41] and elsewhere [42]. In the arrangement shown in Fig. 17, the third electrode is placed in a favorable position to receive sputtered metal from the cathode. The voltage applied to this electrode is intermediate between the cathode and anode so that the inert gas ions are driven into it with sufficient energy to be embedded but not sufficient to cause appreciable sputtering. Thus gas cleaned up by this electrode is permanent.

Ion pumps offer great promise of replacing many conventional diffusion pumps. Their principal advantages are that the system is never exposed to contamination from diffusion-pump fluids and no refrigerants are necessary. One of their present disadvantages is the difficulty of pumping large quantities of organic vapors of high molecular weight such as benzene and toluene at pressures above 10^{-5} mm Hg. Another disadvantage is their inability continually to pump large amounts of gas at high pressure because of excessive cathode heating and sputtering.

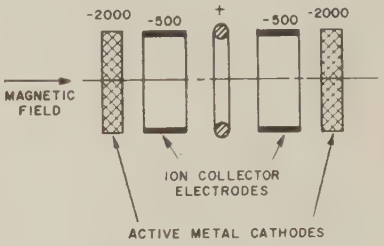


Fig. 17—Three-electrode ion pump.

Cryogenic Pumps

Immersion of the whole or part of a vacuum system in liquid air or immersion of a trap containing charcoal in liquid air was a convenient way of producing low pressures in the days before the advent of diffusion pumps. In recent years with the need for large systems for space simulation and routine experiments at ultra-high vacuum, cryogenic pumping is again becoming popular. At liquid-helium temperatures, only helium and hydrogen have appreciable vapor presseses. All other gases condense out on the surface of the cooled container. The sticking probability for most gases approaches unity as the temperature is lowered, and the total pressure can be reduced to the ultra-high vacuum range in the absence of hydrogen or helium. If hydrogen or helium are present in quantities greater than monolayer amounts, they can be removed by other means such as ion pumping. The speed of a cryogenic pump is determined by the area of the cold surface and the conductance of the connecting tubing.

For the efficient design of a cryogenic pump, it is necessary to reduce the radiation incident on the trap from the walls of the vessel. The helium trap is normally jacketed by liquid nitrogen.

Cryogenic pumping shows much promise for large specialized system applications such as space-simulation chambers. The General Electric Missile and Space Vehicle Department in Philadelphia, Pa., is constructing a gigantic space simulator using low-temperature gaseous helium-cooled walls as pumps.

Ultra-High Vacuum Components

Since mercury cutoffs, standard stopcocks, and rubber gaskets are not bakeable, their use in ultra-high vacuum systems is prohibited. Stopcock grease, mercury or other fluids used in cutoffs tend to contain large amounts of occluded gas. This has led to the development of a new line of hardware components for ultra-high vacuum systems.

Vacuum Tubes

Alpert [35] has developed a tube (Fig. 18) which can withstand bakeout at ~450°C and has a sufficiently large conductance for ultra-high vacuum systems. Since then there have been many improvements in this general type of tube [43]. A popular commercially available tube is made by the Granville-Phillips Corporation of Pullman, Wash., and is shown in Fig. 19. This particular tube has a conductance variable from one liter/sec to less than 10^{-14} liter/sec.

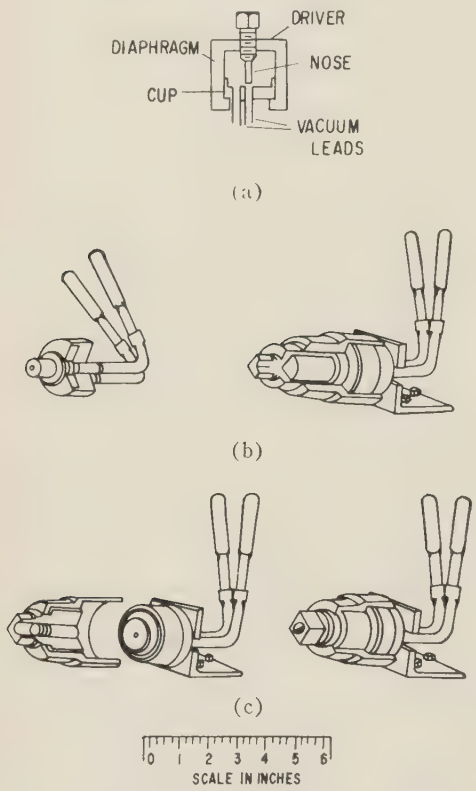


Fig. 18—Ultra-high vacuum bakeable metal valve (Alpert). (a) Schematic diagram. (b) Tube with differential screw-driving mechanism. (c) Tube with simple screw-driving mechanism.

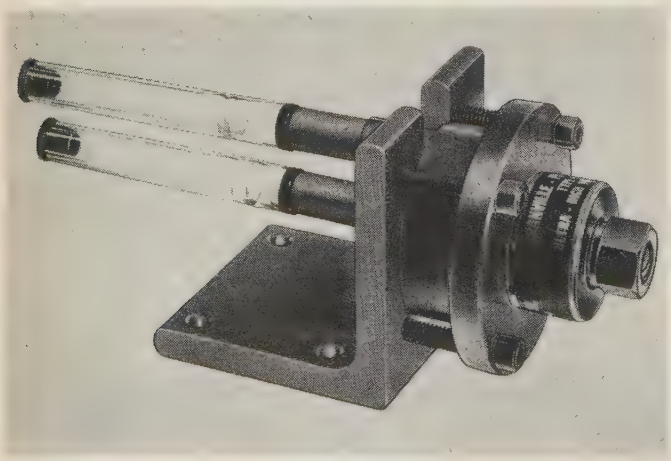


Fig. 19—Granville-Phillips tube.

Molten-metal tubes are becoming more popular [44]. The advantage of this type of tube over ordinary mercury cutoffs is that the metal is a solid at room temperature having a low vapor pressure. The metal is raised into the seal-off position while the tube is hot and then is allowed to solidify by cooling and this completes the seal. They lack some of the convenience of other types of tubes, but have the advantage of simplicity.

Demountable Seals

The convenience of a demountable seal is often desired even in an ultra-high vacuum device. The usual device consists of a metal gasket crushed between two flanges [35], [45]. The gasket metal is selected for its ductility as well as its low vapor pressure at bakeout temperatures. Pattee [46] described a demountable joint which was used in a field-emission apparatus. The seal (Fig. 20) consists of a knife edge which seats in an annealed copper gasket. The knife edge is machined on heavy wall stainless-steel tubing. It has a 0.005-inch radius at the tip and a 45° wedge angle. Adjustment is permitted by deformation of the copper by the clamping screws.

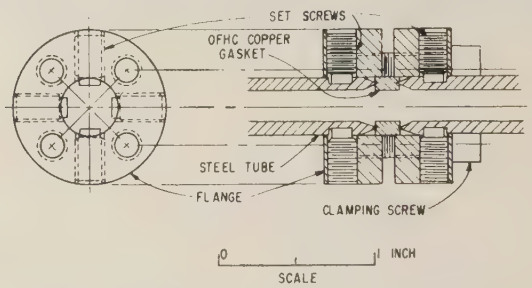


Fig. 20—Demountable vacuum seal (Pattee).

Modern Vacuum Systems

A major requirement of an ultra-high vacuum system is that the system be capable of being baked at high temperatures. This is most conveniently done by having a furnace placed around the entire vacuum system. There are many possible arrangements and one which has been found convenient in this laboratory is shown in Fig. 21. Two walls of the oven are fixed permanently in place. These can be made of insulated stainless-steel or asbestos board. The vacuum components, such as tubes, are attached directly to the surface with flexible glass bellows or long glass U bends inserted between each fixed point. Lightweight insulated aluminum modular ovens are placed over the system during bakeout and the temperature is controlled by any convenient pyrometer. Only a number of the heating units (Cal-rods) is controlled by the pyrometer and the others are controlled manually. If it is desired to bring the system quickly to temperature, the manually-controlled Cal-

rods are turned on. When the bakeout temperature is approached, these heating units are turned off and the automatically-controlled Calrods maintain the temperature in the vicinity of the desired value. The automatically-controlled heating units do not have enough power to heat the oven more than 50°C above the desired temperature. In this manner, if the controller fails to function, there is less danger of melting the glassware. In practice, however, the automatically-controlled heaters are used to bring the furnace to temperature in a few hours.

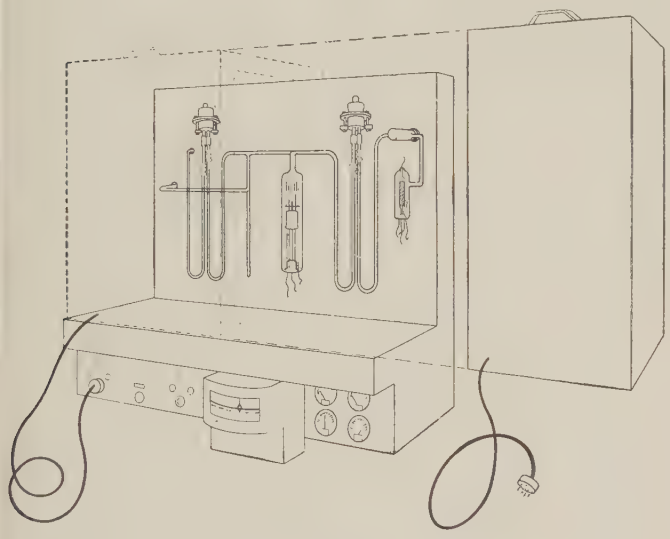


Fig. 21—Typical laboratory ultra-high vacuum system.

The procedure is much the same whether mercury, oil or ion pumps are used. The system is first pumped to $\sim 10^{-6}$ mm Hg and a cursory check for leaks is made. The ovens are usually placed over the system and the automatic controller is set to the desired temperature. The entire system, including the traps, back to the pumps is baked at 425°C. After four or five hours at 425°C, the furnace on the trap closest to the pump is shut off. With mercury pumps, the trap is cooled by a Dewar filled with liquid nitrogen. When alumina traps are used in conjunction with oil diffusion pumps, the trap is simply allowed to cool to room temperature. With ion pumps no trap is needed. A common procedure is to use two ion pumps in sequence, one of which is baked out and the other is used to pump the system during bakeout. When mercury or oil pumps are used the system is kept hot for approximately four hours after the traps have cooled before allowing to cool slowly to room temperature. The ovens are removed and the pressure of the system is checked with an ionization gauge, and a check is made for small leaks. The detection of leaks is quite simple in the pressure range below 10^{-8} mm Hg. Acetone and carbon tetrachloride, for example, applied to a small leak cause the positive-ion current reading on the ionization gauge to increase suddenly, or they clog the leak temporarily and cause the current to decrease. Helium and hydrogen can also be used with success. Measurement of the rate of rise of pressure also will detect a leak, and by shutting off various sections of the system, the leak can be isolated. Final pin-pointing is usually done with the ionization gauge. If no leaks are found, the metal parts are outgassed at high temperatures by electron bombardment or by RF heating. In some cases a second bakeout is done after the outgassing and pressures of 10^{-10} mm Hg are routinely obtained.

Leak Detectors

To the experimenter interested in using vacuum systems, one of the greatest problems is leaks. Leaks may occur from a variety of causes, and the increasing complexity of tube design has multiplied the number of these causes to a great extent. The time-honored method of detecting leaks in glass systems by means of a Tesla spark coil has become obsolete with all-metal vacuum systems. Leak detectors involving a change in thermionic emission caused by an adsorbed layer of gas on the filament of a diode or ionization gauge have been used successfully as described in the previous section. The present trend in leak detection is towards the sensitive high-speed helium mass spectrometer. The development of a new leak detecting process using radioactive gas has made it possible to detect leaks in sealed systems or devices without destruction or opening to air. Some of the leak detectors of current interest are described below.

Mass Spectrometers

A very sensitive method for the detection of leaks, and one which also gives an indication in a minimum of time, was developed by Jacobs and Zuhr [47]. It involves the use of a mass spectrometer with helium [48], and the principle by which it operates may be described briefly as follows: When a beam of positive ions, accelerated by a potential V, is passed through a magnetic field of strength H, the ions are sorted out according to their values of e/m, where m is the mass of the ion and e the charge. The radius of curvature R of the path of any given type of singly-charged ion is determined by

$$R = 143.9 \frac{\sqrt{MV}}{H}, \qquad (6)$$

where R is expressed in centimeters, V in volts, H in oersteds, and M is the molar mass of the ion in grams.

For example, for $R = 4.0$ cm and $H = 1500$ oersteds, the values of V for helium ($M = 4.003$) and nitrogen ($M = 14.008$, since N^+ is formed), are found to be 434 and 124 v, respectively. Thus, for a given value of the radius of curvature, the ions reaching a collector may be differentiated by varying the value of V, and the mag-

nitude of the ion current at any given voltage setting will depend on the concentration of the ions in the beam, that is, on the rate at which the corresponding molecules leak into the spectrometer.

For the detection of leaks, helium has been chosen as testing gas for the following reasons:

1. Because of the low value of M, the rate of diffusion through a leak is greater than that of any other gas except hydrogen.
2. Helium occurs in the atmosphere to the extent of only one part in 200,000 parts of air.
3. There is little possibility that an ion due to any other gas will give an indication that can be mistaken for helium.

The application of the mass spectrometer to the detection of leaks has been described in two papers, one by Worcester and Doughty [49] and the other by Thomas, Williams, and Hipple [50].

A modern version of the helium mass spectrometer leak detector is shown in Fig. 22. This instrument is capable of detecting leaks as small as 10^{-10} cc of air per sec in evacuated enclosures. Such a leak is so small that more than 5000 years would be required for one cubic inch of air at atmospheric pressure to pass through the opening. For pressurized enclosures leaks down to 10^{-6} cc per sec can be located. In this spectrometer the helium ions are deflected through 90° by the magnetic field. The current generated by collection of the helium ions is amplified and used to indicate a leak on the leak-rate meter and on an audible alarm. The components to be leak checked are connected to a manifold which is first exhausted by the mechanical roughing pump, and when the pressure, as indicated, for instance, by a thermocouple gauge connected to the test manifold is sufficiently low the throttle valve to the spectrometer tube is opened. A fine jet of helium is passed over suspected parts in each of the tubes, and the presence of a leak is indicated on the leak-rate meter.

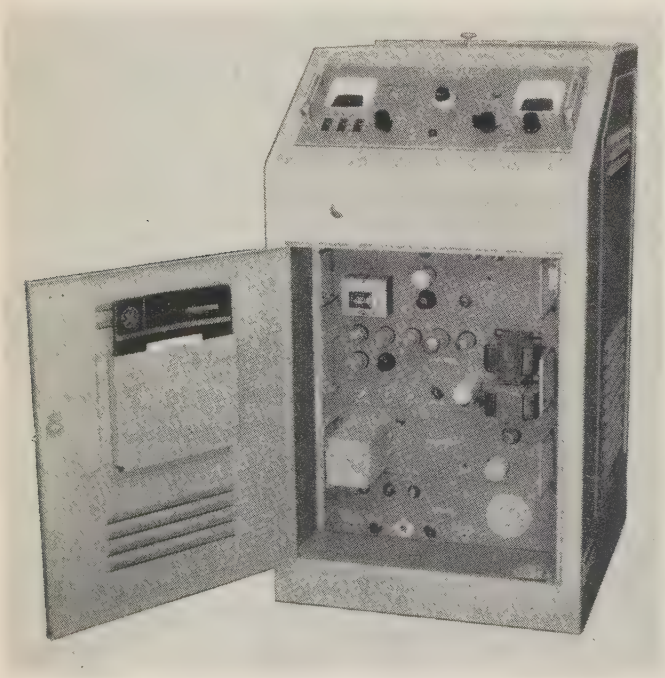


Fig. 22—Mass-spectrometer leak detector (General Electric, M-60).

Fast leak testing is made possible with this spectrometer by the incorporation of an automatic balance circuit. This circuit allows the leak detector to respond only to a rapid increase in helium signal such as obtained when a jet of helium passes near a leak. When large systems are being tested, large leaks are sometimes encountered with the jet of helium which cause the mass-spectrometer vacuum system to become partially saturated with helium. Normally, the operator would have to wait a considerable time before the helium has been pumped out of the system to a point where leak testing can be resumed. However, with the automatic balance circuit the helium background is balanced out and a leak signal is given only when the operator passes the jet of helium near a leak.

Radiflow Method

A new method of leak testing hermetically-sealed components nondestructively by utilizing a radioactive gas has been described by Cassen and Burnham [51]. Leakage rates in the order of 10^{-12} cc per sec can be measured under favorable conditions by this process called "radiflo." Equipment for this leak detection system is manufactured by the Analytical and Control Division of Consolidated Electrodynamics Corporation, Pasadena, Calif. The basic principle involves the detection of radioactive krypton 85 which has been allowed to diffuse into the leaky components. Krypton 85 has a half-life of 10.3 years. Over 99 per cent of the disintegrations involve the emission of beta rays with a maximum energy of 0.67 Mev, while only 0.7 per cent of the disintegrations give 0.54-mev gamma rays. The gamma emitting disintegrations are used to detect the leaks since the gamma rays will pass readily through most materials. Detection of the beta rays may be used under some circumstances to determine the presence of occluded krypton on the surface of the components under test. The testing procedure is as follows: The components to be tested are placed in an activating tank which is then sealed. Air in the tank is evacuated down to approximately 2 mm Hg and diluted krypton 85 is pumped into the tank under pressure up to 7 atmospheres. The radioactive gas diffuses into existing leaks in the components. After a prescribed "soaking" period, which may be from several minutes to a few hundred hours, the krypton is pumped out of the activating tank and returned to storage for reuse. If the leaks follow Poiseuille's Law, the quantity of krypton diffusing into leaky components will increase with the square of the pressure and linearly with time. Thus a suitable combination of krypton pressure and "soaking" time may be selected to give the desired sensitivity. Next, an air wash is circulated over the components to remove any residual krypton from the external surfaces. The com-

ponents are then removed from the activating tank. Those with leaks will retain some radioactive atoms which emit gamma radiation. This radiation is detected by a scintillation counter and the intensity is determined by a ratemeter. When this radiation intensity is related to the conditions of the activation process, the leak rate may be determined.

Some components may have absorptive surfaces such as organic coatings, gaskets, or insulation which will retain krypton 85 for various lengths of time after the pressure is released. The gamma radiation emitted by this absorbed gas could make the components appear as leakers when, in fact, they are not. A routine check of rejected parts with a thin-window Geiger-Müller counter tube for beta ray activity reveals surface contaminations.

Halogen-Ion Detector

Quite different in principle from all the other methods of leak detection described above is that involved in the positive-ion detector for halogen compounds which has been described by White and Hickey [52].

Some of the earliest investigators in the field of thermionic emission, such as O. W. Richardson, had observed that platinum, even in air at a temperature of a red heat, emits positive ions, and that the rate of ion emission increases with temperatures according to a relation similar to that observed for electron emission from incandescent cathodes. This positive-ion emission is probably due mostly to the presence in the anode of salts of the alkali metals, although this may not be the correct interpretation of the mechanism of operation of the device described below.

It was observed by C. W. Rice of the General Electric Company that this emission, at any given anode temperature, of positive ions in air is increased very markedly when vapors of compounds containing a halogen strike the electrode surface. This observation forms the basis of the detector developed and described by White and Hickey.

A diagrammatic sketch of the device and simple circuit used for its operation are shown in Fig. 23. The detector consists of a platinum cylinder P which is heated by an insulated platinum filament F, the low voltage required for this purpose being supplied by the transformer T. A metal cylinder C, concentric with P, is connected through a microammeter (μA) to the negative end of a dc source of voltage (50–500 v) while P is connected through the midpoint of the secondary of T to the positive end of the voltage source.

In using the device for detection of leaks, air or any other suitable gas containing a halogen vapor is introduced into the system at a positive pressure. This positive pressure forces the air containing the halogen out through the leak where it may be picked up by the device and is indicated by the meter in the detector circuit. Or the detector may be sealed on the vacuum system in series with the pump (preferably between the rough and the fine pumps). Air containing a halogen vapor is forced under pressure through a very small jet and directed at any suspected spot in the system and then is picked up by the detector.

In using the detector, the temperature of the anode should be between 850°C and 950°C. At lower temperatures, the positive-ion emission is too small, and at higher temperatures the emission becomes unstable. Typical halogen compounds which are fairly volatile at room temperatures and therefore applicable in using the positive-ion detector are "Freon," carbon tetrachloride, and chloroform.

A convenient form of the halogen-leak detector is shown in Fig. 24. The unit contains a power supply, amplifier, sensing element and an air pump. The detector probe is connected to the control unit through a flexible cable. Air drawn in at the probe passes through

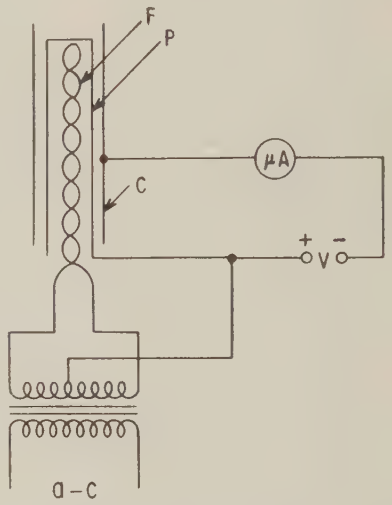


Fig. 23—Schematic diagram of the thermionic detector and circuit used for detection of halogen compounds (White and Hickey).



Fig. 24—Gun-type halogen leak detector (General Electric, H-2).

the sensing element and is exhausted through the pump. When the probe is moved so as to pass near a leak, the sudden increase of halogen gas mixing with the air going into the probe will cause an increase in the detector ion emission. This current is amplified and measured on the leak-rate meter. The detector may be used to locate leaks down to 5×10^{-5} cc/sec in an atmosphere with contamination up to 1000 parts of halogen gas per million parts of air.

The halogen-leak detector has a special advantage in that no helium is required. This has given this method preference in instances where scarcity of helium has been a problem [53].

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New Concepts in Thermoelectric Device Design*

W. H. CLINGMAN†

Summary—When optimizing thermoelectric device design for a given set of materials and technology, the system of equations used will be different for various device applications. Whenever efficiency or coefficient of performance is important in the application, an irreversible thermodynamic analysis of the design problem is useful. In this analysis, the effects of the thermal and electrical circuit on entropy production within the device are considered. The design problem is analyzed by comparing the relative contribution of various parts of the system to the total entropy production. This irreversible thermodynamic approach is illustrated with examples concerning several different design questions. Often qualitative conclusions can be drawn more readily than with other methods.

Introduction

THE ultimate objectives of industrial thermoelectric research are to increase the coefficient of performance or efficiency and to reduce the cost of Peltier coolers and thermoelectric generators. Increasing the power-to-weight ratio is also significant in some applications. Toward these objectives, new materials with a higher figure of merit or lower cost are being sought and new methods of fabrication developed. The area of research analyzed in this paper, however, is the optimum design of the thermoelectric system itself, using available materials and technology.

A thermoelectric system consists, in general, of both a thermal circuit and an electrical circuit. This is illustrated for a single thermocouple generator in Fig. 1. Usually there are three parts to the system: two junctions, the thermocouple legs, and the thermal resistances, B_H and B_C, between the couple and the heat source and sink. In the legs and junctions, the heat and electrical current flow through the same material. Interconversion of thermal and electrical energy occurs within this material. Heat is added or removed from the thermal circuit by the Peltier effect at the junctions and by Joule and Thomson heating in the legs. These sources of heat current will affect the heat flow through B_H and B_C. Thus, for fixed source and sink temperatures, the junction temperatures will depend on the magnitude of the thermoelectric effects. Alternatively, however, the temperatures of the hot and cold junctions will determine the open-circuit voltage of the couple and the Peltier coefficients. There is a complex interaction between the thermal and electrical circuits involving even that part of the thermal circuit which carries no electrical current.

The equations describing the behavior of the system contain the material properties: thermoelectric power (α), resistivity (ρ), and the thermal conductivity (k).

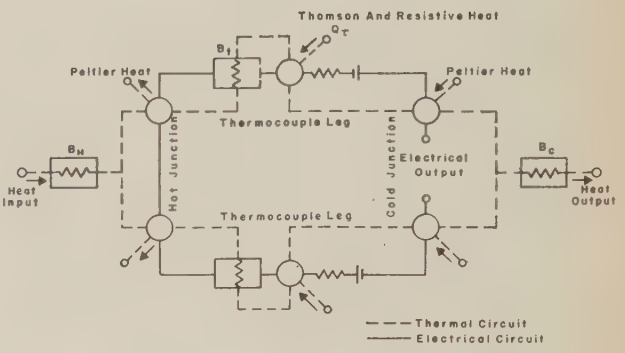


Fig. 1—Thermal and electrical circuits.

Each is a function of temperature, and a digital computer is required for an exact solution. Where B_H and B_C are zero, computer calculations of efficiency and coefficient of performance have been made.[1] Calculations were recently extended to thermocouple legs containing several different materials.[2] Using such calculations or suitable approximations, one can choose device dimensions, within the constraints of a particular application, to maximize efficiency or coefficient of performance.

The nature of the design and the equations to be solved, however, depend upon the particular application. Even the relative importance of various parts of the thermal circuit will depend on the quantity to be optimized. For example, in optimizing the efficiency of a generator, the thermocouple legs are chosen sufficiently long that B_H and B_C are negligible with respect to B_t, the thermal resistance of the legs. The electrical contact resistance of the junctions must be negligible also, with respect to the electrical resistance of the legs. Assuming that the device design is chosen to satisfy these conditons, B_C, B_H, and contact resistance may be set equal to zero in the general equations describing the behavior of the system.

To optimize power output per unit weight of thermoelectric material used, however, the situation is quite different.[3] A new set of approximations will apply in simplifying the general equations, and the design equations used in maximizing efficiency will no longer be applicable. When the thermocouple legs in a maximum

* Received by the IRE, February 28, 1961. Reprinted from the 1961 IRE International Convention Record, pt. 6.

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efficiency design are shortened, the internal resistance of the generator decreases; the open-circuit voltage remains the same; and the power output increases. Shortening the legs, however, is equivalent to reducing B_t, and a point will be reached where B_H and B_C are no longer negligible compared with B_t. The open-circuit voltage will then drop because of temperature changes at the hot and cold junctions. Also, as the legs are shortened, the internal resistance will approach a constant value equal to the contact resistance of the junctions. Thus, the power output will pass through a maximum (Fig. 2). With lead telluride generators, this maximum power output occurs at a design point where both electrical contact resistance and B_C and B_H are significant.[3] In fact, when there is an upper temperature limit for operation of the cold junction (*e.g.*, as required for stability of a soldered contact), the optimum design can be determined by considering only B_t and B_C.[3] To a first approximation, the optimum thermocouple leg length will be independent of the electrical properties of the material.

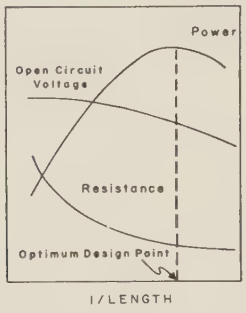


Fig. 2—Designing for maximum power per unit material weight.

Thus, in some design problems the objectives are unrelated to efficiency or coefficient of performance. Whenever these quantities are important, however, an irreversible thermodynamic analysis of the system can be useful. This approach is developed below and illustrated with examples for particular cases.

Irreversible Thermodynamic Analysis

Interpretation of the thermal and electrical circuit interaction shown in Fig. 1 can be simplified by a new description of the system based on irreversible thermodynamic concepts. The thermoelectric generator or cooler can be considered as a basic heat engine shown in Fig. 3. The engine is characterized by specifying the operating temperatures, T_H and T_C; the heat flows in and out of the device, Q_H and Q_C; and the power output, P. In the case of heat pumps, P is the power input. As a result of heat flow, the entropy of the heat source decreases at the rate Q_H/T_H. Similarly, the entropy of the heat sink increases at the rate Q_C/T_C. The thermoelectric system operates in a steady-state condition; therefore, its entropy remains constant with time. The difference between Q_H/T_H and Q_C/T_C is the total rate of entropy production Σ due to irreversible processes in the thermoelectric system.

$$\Sigma = \frac{Q_C}{T_C} - \frac{Q_H}{T_H} . \tag{1}$$

Minimizing Σ is equivalent to optimizing efficiency or coefficient of performance. Various design problems can be treated by first dividing the system into parts and analyzing the entropy production in each part. The design of the parts is then chosen to minimize entropy production. Whenever efficiency or coefficient of performance is important for a particular application, this type of analysis can be used. The method is simpler than considering the details of the thermal and electrical circuits. Several otherwise unrelated design problems can be analyzed in terms of the same concepts. The basic ideas of the irreversible thermodynamic theory will be developed and illustrated with specific examples. The results are of two types, those allowing a choice between different designs, and those giving a guide to materials development.

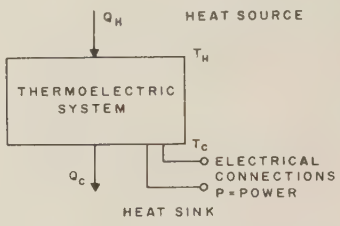


Fig. 3—Basic heat engine.

First, efficiency and coefficient of performance will be related to total entropy production. The efficiency η is defined as

$$\eta = \frac{P}{Q_H} . \tag{2}$$

Also, since energy is conserved,

$$P = Q_H - Q_C. \tag{3}$$

Eliminating Q_H and Q_C from (1)–(3) gives

$$\eta = \left(\frac{T_H - T_C}{T_H}\right) \cdot \frac{1}{1 + T_C \Sigma / P} . \tag{4}$$

The coefficient of performance ϕ of a heat pump is defined as

$$\phi = \frac{Q_C}{P} , \tag{5}$$

where the direction of the heat flows is now reversed. The coefficient of performance is given in terms of the entropy production as follows:

$$\phi = \frac{T_C}{T_H - T_C} \cdot [1 - T_H \Sigma / P]. \tag{6}$$

Eqs. (4) and (6) are the desired results relating device performance to the ratio (Σ/P). In the heat pump, it is necessary that $\Sigma < P/T_H$ for the coefficient of performance to be greater than zero. Thus, the entropy production must be below a certain maximum value before the device will work as a cooler.

Let us now consider the application of these equations to thermoelectric generators with segmented legs, *i.e.*, thermocouple legs containing several different materials. Here, each of the materials may be used over its optimum temperature range for maximum figure of merit Z where $Z = \alpha^2/\rho k$. Sometimes efficiency may be increased by adding a material to the hot side of the thermocouple and operating the new thermocouple over a higher temperature range. This is illustrated in Fig. 4, where material B is added to the thermocouple composed of material A. Material B then operates over the temperature range from T_H to T_1, and material A from T_1 to T_C. The corresponding heat-flow diagrams are shown below the thermocouples. One might expect a higher efficiency of the combined thermocouple [Fig. 4(d)] because of an increase in Carnot efficiency from

$$\left(\frac{T_1 - T_C}{T_1}\right) \text{ to } \left(\frac{T_H - T_C}{T_C}\right).$$

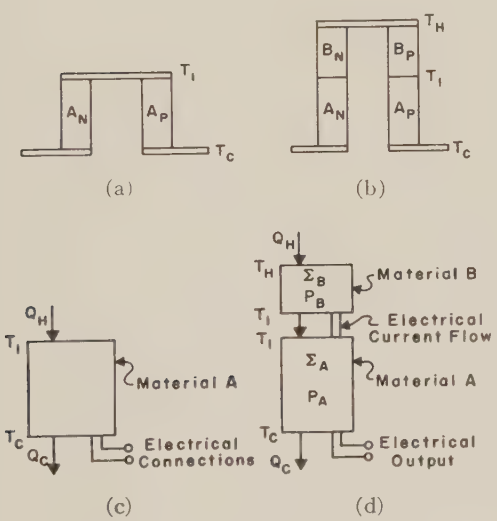


Fig. 4—Adding segments to generator.

If the entropy production in material B is sufficiently high, however, the combined thermocouple efficiency may actually be lower than that of the couple using only material A. The efficiency of the combined couple may be written

$$\eta = \eta_c \cdot \frac{1}{1 + T_C(\Sigma/P)}, \tag{7}$$

where

$$\eta_c = \frac{T_H - T_C}{T_C} = \text{Carnot efficiency.}$$

The entropy and power production in materials A and B are additive. Thus,

$$(\Sigma/P) = \frac{P_A(\Sigma_A/P_A) + P_B(\Sigma_B/P_B)}{P_A + P_B}. \tag{8}$$

The entropy-to-power production ratio for the combined generator is an average of this ratio for each material, with the fraction of the power produced by each material as the weighting factor. Let η^A and η^B equal the efficiencies of generators composed only of part A or B of the combined couple, with the same current as in the combined couple.

$$\eta^A = \frac{T_1 - T_C}{T_1} \cdot \frac{1}{1 + T_C(\Sigma_A/P_A)}$$

$$= \eta_c{}^A \cdot \frac{1}{1 + T_C(\Sigma_A/P_A)}. \tag{9}$$

$$\eta^B = \frac{T_H - T_1}{T_H} \cdot \frac{1}{1 + T_1(\Sigma_B/P_B)}$$

$$= \eta_c{}^B \cdot \frac{1}{1 + T_1(\Sigma_B/P_B)}. \tag{10}$$

For

$$\frac{\eta}{\eta_c} \geq \frac{\eta^A}{\eta_c{}^A},$$

it is necessary and sufficient that $(\Sigma_B/P_B) \leq (\Sigma_A/P_A)$. This relation gives the upper limit to the entropy production in part B so that the fraction of the Carnot efficiency is the same in the combined generator as in the original thermocouple.

A more quantitative relation between the efficiencies, η, η^A, and η^B can be obtained from (8) by expressing the entropy-to-power production ratios in terms of these efficiencies. The result is as follows:

$$\frac{P}{T_C}\left[\frac{\eta_c}{\eta} - 1\right] = \frac{P_A}{T_C}\left[\frac{\eta_c{}^A}{\eta^A} - 1\right] + \frac{P_B}{T_1}\left[\frac{\eta_c{}^B}{\eta^B} - 1\right] = \Sigma. \tag{11}$$

This equation merely states that the total entropy production is the sum of the entropy production in materials A and B.

We will now consider a second application of these concepts. In the combination shown in Fig. 5, a pure thermal resistance is inserted between the thermoelectric generator and the heat sink. The heat transfer coefficient h_C of the thermal resistance is defined as

$$h_C = \frac{Q_C}{A(T_1 - T_C)}, \tag{12}$$

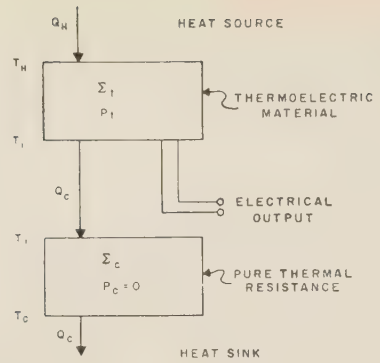


Fig. 5—Analysis of thermal resistance for a generator.

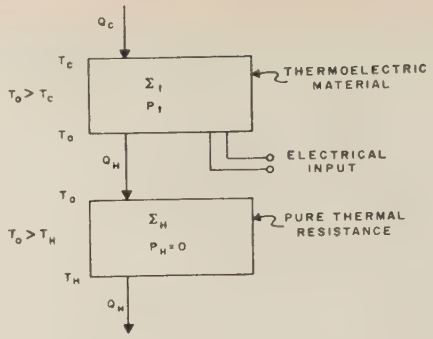


Fig. 6—Analysis of thermal resistance for a heat pump.

where A is the heat transfer area. The question to be analyzed is the condition on h_C for the thermal resistance to have a negligible effect on efficiency. The total entropy production is again divided in two parts, that produced in the thermoelectric material and that produced in the thermal resistance.

$$\eta = \frac{T_H - T_C}{T_H} \cdot \frac{1}{1 + T_C[\Sigma_t + \Sigma_C]/P_t} \cdot \tag{13}$$

The above requirement on h_C can be expressed as

$$\Sigma_C \ll \Sigma_t. \tag{14}$$

When (14) is satisfied, $T_1 \approx T_C$, and Σ_t is given as

$$\Sigma_t \approx \frac{P_t}{T_C}\left[\frac{\eta_c}{\eta} - 1\right]. \tag{15}$$

In addition,

$$\Sigma_C = Q_C\left[\frac{1}{T_C} - \frac{1}{T_1}\right] \approx \frac{Q_C^2}{Ah_C} \cdot \frac{1}{T_C^2}$$

$$Q_C = P_t\left(\frac{1}{\eta} - 1\right). \tag{16}$$

$$\therefore\ h_C \gg \frac{P_t}{AT_C}\left[\frac{1}{\eta} - 1\right]^2 \Big/ \left[\frac{\eta_c}{\eta} - 1\right]. \tag{17}$$

To assess the order of magnitude of the right-hand side of (17) assume that $P_t/A = 1$ watt/cm^2; $\eta = 0.05$; $T_C = 300$°K; and $T_H = 500$°K. Then (17) becomes $h_C \gg 0.17$ watt/cm^2-°C. The heat transfer coefficient of metal-insulator contacts is of the order of 0.5 watt/cm^2-°C or less. Thus, in the example, electrical insulation at the cold end of the generator will lower efficiency somewhat.

A similar analysis can be made for adding thermal resistance to the hot end of a heat pump. A heat-flow diagram for this case is given in Fig. 6. Coefficient of performance is given by

$$\phi = \frac{T_C}{T_H - T_C}[1 - T_H(\Sigma_t + \Sigma_H)/P_t]. \tag{18}$$

The requirement for a negligible effect of thermal resistance on coefficient of performance is now given by

$$T_H \frac{\Sigma_H}{P_t} \ll 1 - T_H \frac{\Sigma_t}{P_t} \cdot \tag{19}$$

Evaluting Σ_t and Σ_H as before gives

$$h_H \gg \frac{Q_C}{AT_H}\left(\frac{1}{\phi} + 1\right)^2 \phi_c, \tag{20}$$

where

$$h_H = \frac{Q_H}{A(T_C - T_H)}$$

= heat transfer coefficient of thermal resistance,

and

$$\phi_c = \frac{T_C}{T_H - T_C} = \text{Carnot maximum for coefficient of performance.}$$

If the heat pump is operated close to the maximum possible temperature difference, ϕ is small, and h_H must be large to avoid having a significant effect on performance. Assume that with $T_H = 300$°K, the maximum temperature difference for the couple is 70°K. Eq. (20) will be evaluated for the following operating conditions: $T_H = 300$°K; $T_C = 240$°K; $Q_C/A = 1$ watt/cm^2. Under these conditions and at the current for maximum heat pumping, $\phi = 0.0571$ and $\phi_c = 4.0$. Eq. (20) becomes

$$h_H \gg 4.6 \text{ watts/cm}^2 - \text{deg}. \tag{21}$$

It would be impossible to satisfy this equation from a practical standpoint, and electrical insulation at the hot junction would have a very significant effect on thermocouple performance.

In the examples given, the system was divided in two parts, and the contribution of each part to the total entropy production was analyzed. It is also possible to subdivide the system into a large number of parts by isothermal surfaces through the device. One can then consider the local entropy production ($\sigma\Delta T$) and power production ($p\Delta T$) in the material between two isothermal surfaces differing by a small temperature increment, ΔT (Fig. 7). In general, σ and p are functions of

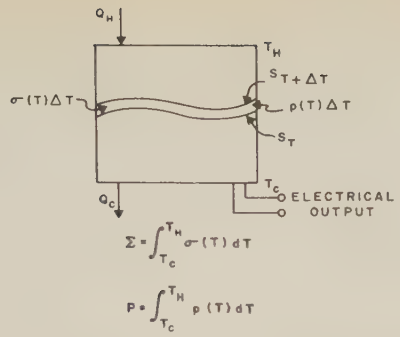


Fig. 7—Local entropy and power production.

temperature throughout the system. This approach is advantageous because the local entropy and power productions at temperature T can be simply expressed in terms of the thermal and electrical currents crossing the isothermal surface S_T and the thermoelectric properties of the material at T. If at each temperature there are only two thermoelectric materials, N and P types, then σ and ρ are given by the following:[4]

$$\sigma(T) = \frac{1}{T^2}(Q_P + Q_N) + \frac{I^2}{T}\left[\frac{(\rho k)_P}{Q_P} + \frac{(\rho k)_N}{Q_N}\right] \tag{22}$$

$$\rho(T) = I(\alpha_P - \alpha_N) - I^2\left[\frac{(\rho k)_P}{Q_P} + \frac{(\rho k)_N}{Q_N}\right], \tag{23}$$

where I is electrical current, and Q_P and Q_N are the heat flows in the P and N type material, respectively. For generators, $I>0$; for coolers, $I<0$. The first term in the expression for σ is due to irreversible heat conduction and the second term to irreversible Joule heating. The expression for power production contains a term related to the Seebeck voltage and a second term to correct for the I^2R loss. In the case of coolers the convention is made that $\rho(T)<0$.

Eq. (4) for efficiency now becomes

$$\eta = \frac{T_H - T_C}{T_H} \cdot \frac{1}{1 + T_C \int_{T_C}^{T_H} \rho(T)[\sigma/\rho]dT \Big/ \int_{T_C}^{T_H} \rho(T)dT} \cdot \tag{24}$$

The total entropy-to-power production ratio, Σ/P, is an average over the ratios, $\sigma(T)/\rho(T)$, corresponding to each temperature in the system. The function $\rho(T)$ is the weighting factor in the average. The efficiency depends not only on the local entropy-to-power production ratios, but also on the weighting factors $\rho(T)$ at each temperature.

[4] W. H. Clingman, "Entropy Production and Optimum Device Design," presented at Symp. on Thermoelectric Energy Conversion, Dallas, Tex.; January 8–13, 1961.

By a more detailed irreversible thermodynamic analysis of the system it is possible to relate the efficiency to the ratios, $\sigma(T)/\rho(T)$, only.[4] The expressions for efficiency and coefficient of performance then become

$$\eta = 1 - \exp\left[-\int_{T_C}^{T_H} \frac{\xi(T)}{T}\,dT\right]$$

$$\phi = 1 \Big/ \left\{\exp\left[-\int_{T_C}^{T_H} \frac{\xi(T)}{T}\,dT\right] - 1\right\}, \tag{25}$$

where

$$\xi(T) = \frac{1}{1 + T\sigma(T)/\rho(T)} \cdot$$

With these equations, optimum device design can be considered from the standpoint of minimizing $\sigma(T)/\rho(T)$ at each temperature in the system. When (22) and (23) are substituted in the expression for $\xi(T)$, one obtains the following:

$$\xi(T) = \frac{I(\alpha_P - \alpha_N) - I^2[(\rho k)_P/Q_P + (\rho k)_N/Q_N]}{I(\alpha_P - \alpha_N) + 1/T[Q_P + Q_N]} \cdot \tag{26}$$

For generators, $\xi(T)<1$; and for coolers, $\xi(T)>1$. For any given values of the material parameters and current, there will be optimum heat fluxes, Q_N° and Q_P°, for each leg. These optimum heat fluxes will maximize ξ for generators and minimize ξ for coolers. The optimum ratio in either case is given by

$$\frac{Q_P^\circ}{Q_N^\circ} = \frac{(\rho k)_P{}^{1/2}}{(\rho k)_N{}^{1/2}} \cdot \tag{27}$$

In theory, this optimum ratio could be achieved by adjusting the ratio of the areas of the two legs and by transferring heat from one leg to the other at intermediate temperatures. If it is assumed that $Q_P/Q_N = (\rho k)_P{}^{1/2}/(\rho k)_N{}^{1/2}$, (26) can be simplified to

$$\xi(T) = [1 - (1/ZT)(1/c)]/[1 + c], \tag{28}$$

where

$$Z = \frac{(\alpha_P - \alpha_N)^2}{[(\rho k)_P{}^{1/2} + (\rho k)_N{}^{1/2}]^2}$$

= the device figure of merit evaluated from material properties at the temperature T,

and

$$c = \frac{Q_P + Q_N}{I(\alpha_P - \alpha_N)T} = \text{a dimensionless heat flux.}$$

In general, both Z and c are functions of temperature. The figure of merit Z depends only on the thermoelectric materials used, while c depends on both the materials and the device design.

In Fig. 8, $\xi(T)$ is shown as a function of c for three values of ZT. The curves for negative values of c correspond to cooler performance and those for positive c,

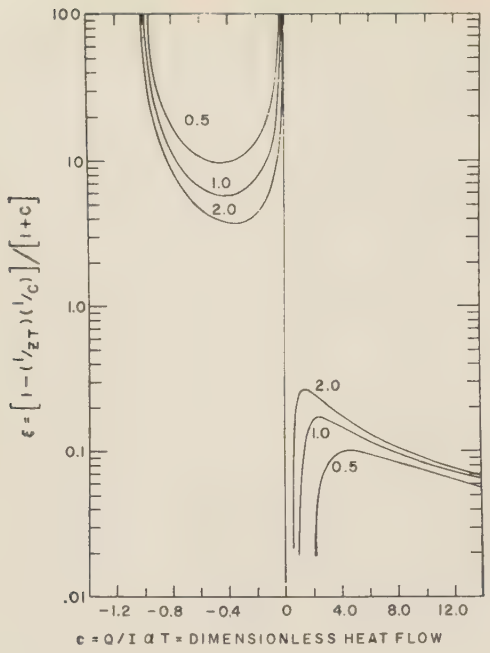


Fig. 8—Variation of ξ with dimensionless heat flow.

to generators. To illustrate the interpretation of these curves, consider a generator for which ZT has the constant value of 0.5 over its entire operating range. For optimum efficiency, the device should operate at a constant value of c equal to 4.5. For two reasons, however, c will increase as one moves from the hot to the cold junction: 1) (Q_P+Q_N) increases due to Joule heating in the legs and 2) temperature appears in the denominator of c. Two methods may be used to keep c constant. First, the device design can be changed from a single stage to several stages between the heat source and sink.[5] In this case, changing the current adjusts c toward its optimum value between each stage. Second, if the Thomson effect absorbs heat and is of sufficient magnitude, it can counter-balance the Joule heating and keep c from increasing with decreasing temperature. Every thermoelectric material has an optimum value for its Thomson coefficient at a given temperature, and this optimum value depends on the other material properties at this temperature.[4]

The advantage gained by these techniques can be judged from the curves in Fig. 8. The wider the range in c for a device, the greater the deviations from the optimum value of ξ. For example, in a lead telluride generator (n-type doped with 0.03 per cent PbI_2 and p-type doped with 0.3 per cent Na) operating between 425°K and 825°K at the maximum efficiency current, $c(T_H)=4.3$ and $c(T_C)=9.5$. The average value of ZT over this temperature range is 0.48. The value of ξ varies from 0.10 to 0.076. The efficiency is 6.07 per cent, and the efficiency with ξ constant at 0.10 is 6.68 per cent.

[5] T. C. Harmon, "Multiple stage thermoelectric generation of power," *J. Appl. Phys.* vol. 29, pp. 1471–1473; October, 1958.

In this case, operation is over the slowly varying part of the ξ-c curve and there is little advantage in staging. However, the range of c increases as the temperature range is extended and several materials are used in a single generator leg. In this case, staging will be a greater advantage.

Approximate calculations of efficiency or coefficient of performance are made by analyzing a device composed of fictitious material. The parameters of this material are chosen as close as possible to those of the real material. The approximate calculation may be interpreted in terms of the functions $\xi(T)$ and $c(T)$. Let the approximate values of the two quantities be denoted by $\xi'(T)$ and $c'(T)$. If a generator is operating over the slowly varying part of the ξ-c curve, errors in the figure of merit and c' will cause only small errors in ξ'. Also there will be some temperatures at which ξ' is too high and some where it is too low, resulting in error cancellation when evaluating the efficiency (25). Approximate generator efficiency calculations are in excellent agreement with exact computer calculations.[1,2]

In some parts of the ξ-c curve, ξ varies rapidly with c. This is particularly true when $|c|$ is close to zero. When heat pumps operate close to their maximum temperature difference, c will approach zero at the hot end of the device. In this case, small errors in c' will make large errors in ξ'. For this reason the relative importance of the Thomson effect on the value of ξ will be greater, and staging will be more significant than for most generators. By staging, the absolute value of the entropy-to-power production ratio is decreased, allowing a greater temperature difference to be maintained between the junctions.

Conclusions

The exact interaction between the thermal and electrical circuits in a thermoelectric device is quite complex. In design analysis simplifying assumptions are normally made, and these will depend on the particular device application. Thus, the actual system of design equations used will vary with the application. In some cases efficiency and coefficient of performance will be unrelated to design objectives. Whenever these quantities are important, however, an irreversible thermodynamic analysis of the system is useful.

In all examples of this approach, the design problem was analyzed by determining the relative contribution of various parts of the device to the total entropy production. This approach often has the advantage of simpler equations, allowing qualitative conclusions to be drawn more readily. In addition, several different design questions can be analyzed in terms of the same concepts.

Acknowledgment

The author appreciates many helpful discussions with R. G. Moore, M. Norwood, and B. R. West of the Central Research Laboratories, Texas Instruments Inc.

IRE Standards on Piezoelectric Crystals: Measurements of Piezoelectric Ceramics, 1961*

61 IRE 14.S1

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* Approved by the IRE Standards Committee, May 12, 1960. Reprints of this Standard 61 IRE 14.S1 may be purchased while available from the Institute of Radio Engineers, 1 East 79th Street, New York, N. Y., at $0.70 per copy. A 20 per cent discount will be allowed for 100 or more copies mailed to one address.

1. Classification of Phenomena

Certain polycrystalline ferroelectric substances, of which ceramic barium titanate ($BaTiO_3$) is the prototype, can be given lasting polar properties, including pyroelectric and piezoelectric effects, by treatment with high electric fields for a short time. The term "to pole" is recommended for this treatment.

Poled ferroelectric ceramics have become an important component in electromechanical devices along with piezoelectric crystals and magnetostrictive materials. The purpose of this standard is to adapt the definitions, relations and measurement methods developed for piezoelectric crystals in general [1]–[3] to ferroelectric ceramics. The higher symmetry of these ceramics leads to simpler relations than for most piezoelectric crystals. The high coupling constants, low mechanical quality factor Q, and noticeable dielectric loss factor of the ferroelectrics, on the other hand, limit the applicability of some approximation formulas of the 1957 and 1958 Standards. Piezoelectric ceramics are sometimes also referred to as "electrostrictive." The choice of designation depends on the degree of penetration into the basic mechanisms involved, but the formalism of piezoelectricity is applicable within the limits stated in the following sections.

1.1 Symmetry Relations

Poled ferroelectric ceramics in their normal operating range show substantially linear relations between stress and strain components on the one hand and electric field and displacement components on the other, just as do piezoelectric crystals, and are called piezoelectric ceramics for this reason. However, with ferroelectric crystals and poled ceramics these relationships are linear only over limited ranges of the input signal. In addition, mechanical and dielectric loss factors are functions of mechanical strain and electric field, respectively.

The symmetry elements of poled ferroelectric ceramics are an axis of rotation of infinite order in the direction of polarization and the infinite set of all planes parallel to that axis as reflection planes. This axis, chosen as the Z axis, is polar. Any direction perpendicular to the Z axis may be chosen as X axis. The set of independent elastic, piezoelectric, and dielectric constants[1] different from zero for this symmetry are

$$s_{11},\ s_{33},\ s_{55},\ s_{12},\ s_{13};\ d_{31},\ d_{33},\ d_{15};\ \epsilon_{11},\ \epsilon_{33}.$$

Additional coefficients are given by the symmetry relations

$$s_{22} = s_{11};\ s_{23} = s_{13};\ s_{44} = s_{55};\ s_{66} = 2(s_{11} - s_{12});$$

$$d_{32} = d_{31},\ d_{24} = d_{15};\ \epsilon_{22} = \epsilon_{11}.$$

This is the same set as for the dihexagonal polar crystal class ($6\ mm = C_{6v}$).

1.2 Electrostrictive Effects

Before poling, the ferroelectric ceramic material is isotropic and shows no piezoelectric effect. For small applied signals ordinary electrostrictive effects are present; there is a strain proportional to the square of the applied electric field and a change in permittivity proportional to an applied mechanical stress. For high electric fields hysteresis effects are pronounced, and it is not possible to derive electromechanical behavior from electrostrictive coefficients relating strain to field strength. Total strain is, however, found approximately proportional to the square of the total electric displacement. Linear terms are thus obtained in a relation between an applied small signal electric displacement and the change in strain caused by this signal. If vectorial superposition of remanent and signal displacement is assumed, and dependence of dielectric and electrostrictive coefficients on magnitude of displacement is disregarded, the following relations between piezoelectric and electrostrictive coefficients result:[2]

$$\begin{aligned} d_{31}/\epsilon_{33}^T &= g_{31} = 2q_{31}D_0, \\ d_{33}/\epsilon_{33}^T &= g_{33} = 2q_{33}D_0, \\ d_{15}/\epsilon_{11}^T &= g_{15} = 2(q_{33} - q_{31})D_0, \\ d_p/\epsilon_{33}^T &= g_p = 4q_{31}D_0, \\ d_h/\epsilon_{33}^T &= g_h = 2D_0(q_{33} + 2q_{31}). \end{aligned} \tag{1}$$

Measurements indicate the assumptions upon which these relations depend are valid in rough approximation. Refined relations have been derived [4], [5].

1.3 Ferroelectric Crystals and Ceramics

Ferroelectric single crystals in general have lower symmetry than the poled ceramic form of the same substance. For this reason measurement methods described in this Standard do not in all cases apply to ferroelectric single crystals. The 1958 Standards on Piezoelectric Crystals describe measurement methods for the most general symmetry conditions, and are, therefore, applicable to ferroelectric single crystals or poled ceramics. In both ferroelectric crystals and ceramics, however, the relations between stress and strain components on the one hand and electric field and displacement on the other are linear only over limited ranges of the input signal; higher signals cause domain reversals resulting in gross deviation from linearity.

[1] See Table II at end of Standards for identification of symbols.

[2] All equations in the present Standard are written in rationalized form.

The most widely used piezoelectric ceramic is barium titanate ($BaTiO_3$). Frequently, barium is replaced in part by lead or calcium. Other ceramic systems showing strong piezoelectric effects are lead metaniobate ($PbNb_2O_6$), solid solutions of lead titanate ($PbTiO_3$) with lead zirconate ($PbZrO_3$), and sodium niobate ($NaNbO_3$) with partial replacement of sodium by potassium, lead, or cadmium.

2. Measurement Methods

Methods developed for measurement of dielectric, elastic and piezoelectric constants of crystals are generally applicable to poled ferroelectric ceramics, but the particular properties of the latter make some special methods advantageous. High values of permittivity usually allow one to disregard stray capacitances, and the relatively high internal mechanical damping (low Q) of the material permits the use of relatively crude specimen holders. High values of piezoelectric coupling generally require the use of complete rather than approximate formulas relating $(f_p - f_s)$ with coupling factors.

The properties of ceramics are functions of the preparation process, and are subject to systematic and statistical fluctuations within a given batch. These fluctuations may be caused by inhomogeneous chemical composition, mechanical differences in the forming process, varying shrinkage and chemical modification during firing, and by varying response to the poling treatment. Nevertheless, measured coefficients of ceramics of definite composition and high density (95 per cent or more of crystal density) converge to values which vary no more than 5 per cent for elastic, 10 per cent for piezoelectric, and 20 per cent for dielectric constants. Proper statistical sampling is necessary to obtain representative constants for a given material. To obtain a complete set of constants for a composition, one must either measure each constant on a large number of samples, or make experiments giving ratios of constants, since such ratios are much less variable than the individual constants. Compliances s_{11}^E and s_{12}^E, for instance, may be determined from the resonance frequencies of two contour-extensional modes of a square plate. Compliance s_{11}^E may also be determined from the resonance frequency of a slim transversely poled bar, and s_{55}^D can be calculated from f_p of overtones of the thickness shear mode of the same bar with electrodes applied to another pair of faces. This establishes ratios s_{12}^E/s_{11}^E and s_{55}^D/s_{11}^E, and thus s_{12}^E/s_{55}^D. An outline of a measurement scheme for determining all the piezoelectric, dielectric, and elastic constants in this manner is shown in Table I. Resonance methods of measurement are preferred, and one procedure is described in detail in the next section. Static and quasi-static methods are then described, and finally measurements and terms in the nonlinear or high-signal range are discussed.

TABLE I

Measurement Scheme for Piezoelectric Ceramics

Constants	Specimen and Orientation	Measurement Scheme, or Calculation Method
s_{11}^E, k_{31}, d_{31}	Bar plated on faces perpendicular to Z.	Resonance measurements of the length extensional mode.
s_{11}^D	Bar plated on faces perpendicular to Z.	From above, using $s_{11}^D=(1-k_{31}^2)s_{11}^E$.
ϵ_{33}^T	Bar plated on faces perpendicular to Z.	Measurement of low-frequency capacitance.
s_{55}^D	Bar poled along Z, but with plating on faces perpendicular to X.	Overtones of thickness shear mode of the same bar as above, but with signal field along X.
ϵ_{11}^T	Bar poled along Z, but with plating on faces perpendicular to X.	Measurement of low-frequency capacitance.
ϵ_{11}^S	Bar poled along Z, but with plating on faces perpendicular to X.	Measurement of high-frequency (clamped) capacitance.
k_{15}	Bar poled along Z, but with plating on faces perpendicular to X.	$k_{15}^2=1-\epsilon_{11}^S/\epsilon_{11}^T$.
s_{55}^E	Bar poled along Z, but with plating on faces perpendicular to X.	$s_{55}^E=s_{55}^D/(1-k_{15}^2)$.
s_{11}^E, s_{12}^E	Square plate with faces perpendicular to Z.	Fundamental resonance frequencies of the two contour-extensional modes of a square plate.
s_{12}^D	Square plate with faces perpendicular to Z.	$s_{12}^D=s_{12}^E-k_{31}^2s_{11}^E$.
s_{33}^D, d_{33}, k_{33}	Bar plated on faces perpendicular to Z, and with length along Z.	Resonance measurements of length extensional mode.
s_{33}^E	Bar plated on faces perpendicular to Z, and with length along Z.	$s_{33}^E=s_{33}^D/(1-k_{33}^2)$.
s_{11}^E, k_p, d_{31}	Disk with faces perpendicular to Z.	Resonance measurements of planar extensional mode.
k_t	Disk with faces perpendicular to Z.	Resonance measurements of thickness extensional mode.
d_h	Disk with faces perpendicular to Z.	Measurement of response to hydrostatic pressure.
d_{33}	Disk with faces perpendicular to Z.	$d_{33}=d_h-2d_{31}$.
c_{33}^D	Disk with faces perpendicular to Z.	Overtones f_p of thickness extensional mode.
s_{13}^D	Calculation.	Calculated from c_{33}^D, s_{12}^D, s_{11}^D, and s_{33}^D.
s_{13}^E	Calculation.	$s_{13}^E=s_{13}^D+d_{31}d_{33}/\epsilon_{33}^T$.
ϵ_{33}^S	Calculation.	$\epsilon_{33}^S=\epsilon_{33}^T\left[1-\dfrac{k_p^2+k_{33}^2+2Ak_pk_{33}}{1-A^2}\right]$, where
	or	$A=\dfrac{\sqrt{2}\,s_{13}^E}{\sqrt{s_{33}^E(s_{11}^E+s_{12}^E)}}$
	Plate with faces perpendicular to Z.	Measurement of high-frequency (clamped) capacitance.

Note: s_{12}, s_{13}, and d_{31} are generally negative. k_p is taken to be positive when d_{31} is negative.

TABLE II

LIST OF SYMBOLS*

Symbol	Meaning	MKS Unit	Reference or Equation
c, c'	Aging coefficients.		(21), (22)
c_{33}	Elastic stiffness constant.	newton/meter^2	[1]
C_0	Shunt capacitance of sample.	farad	[2]
C_1	Series capacitance of sample.	farad	[2]
d	Diameter.	meter	
d_{31}, d_{32}, d_{33} } d_{15}, d_{24} }	Piezoelectric strain constants.	meter/volt = coulomb/newton	[1]
d_p	Planar piezoelectric strain constants.	meter/volt = coulomb/newton	[3]
d_h	Hydrostatic piezoelectric strain constants.	meter/volt = coulomb/newton	[3]
D (superscript)	At constant electric displacement.		[1]
D_1, D_3	Electric displacement components.	coulomb/meter^2	
D_0	Remanent or bias displacement.	coulomb/meter^2	[6]
D (Section 3.1)	Dissipation factor.		
E (superscript)	At constant electric field.		[1]
E, E_1, E_3	Electric field and its components.	volt/meter	
f	Frequency.	cycles/second	
f_a	Antiresonance frequency.	cycles/second	[2]
f_r	Resonance frequency.	cycles/second	[2]
f_n	Frequency at maximum impedance.	cycles/second	[2]
f_m	Frequency at minimum impedance.	cycles/second	[2]
f_p	Parallel resonance frequency.	cycles/second	[2]
f_s	Motional (series) resonance frequency.	cycles/second	[2]
Δf	$f_p - f_s$.	cycles/second	[2]
g_{31}, g_{33}, g_{15}	Piezoelectric "voltage" constants.	volt meter/newton = meter^2/coulomb	[1]
g_p, g_h	Piezoelectric "voltage" constants.	volt meter/newton = meter^2/coulomb	
h_{33}	Piezoelectric "stiffness" constant.	volt/meter = newton/coulomb	[1]
H	Dissipated power/unit volume.	watt/meter^3	
i	Order of overtone.		
k_{31}	Transverse coupling factor.		[3]
k_{33}	Longitudinal coupling factor.		(8)
k_{15}	Shear coupling factor.		(9)
k_t	Thickness coupling factor.		(13)
k_p	Planar coupling factor.		[3]
l	Length.	meter	
M	Oscillator figure of merit.		[2]
P	Electric polarization.	coulomb/meter^2	
q_{31}, q_{33}	Electrostrictive constants.	(meter^2/coulomb)^2	[4]
Q	Mechanical quality factor.		[2]
R_1	Series resistance of sample.	ohm	[2]
R_T	Terminating resistance.	ohm	Fig. 1
s_{11}, s_{22}, s_{33} } s_{13}, s_{23} } s_{44}, s_{55}, s_{66} }	Elastic compliance constants.	meter^2/newton	[1]
S (superscript)	At constant strain.		[1]
S_1, S_3	Strain components.		[1]
t (except Sec. 4 and 5)	Thickness.	meter	
t (Sec. 4 and 5)	Time.	second	
T (superscript)	At constant stress.		[1]
T_1, T_3	Stress components.	newton/meter^2	[1]
y	Any time-variable material constant.		
w	Width.	meter	
$\|Z\|$ min	Minimum impedance of sample.	ohm	
ϵ	Permittivity.		†
ϵ_{11}, ϵ_{22}, ϵ_{33}	Permittivity components.	farad/meter	
η_1	Root of a Bessel equation.		(5)
ρ	Density.	kilogram/meter^3	
σ	Cross contraction (Poisson) ratio.		(5)

* For further explanations, see the references indicated in the last column.

† It is customary to list relative dielectric constants K_1, K_3 obtained from ϵ_{11}, ϵ_{33} by division by the permittivity of free space $\epsilon_0 = 8.85 \times 10^{-12}$ farad/meter.

2.1 Resonance Method

2.1.1 General: The resonance method in general is covered in the IRE Standards on Piezoelectric Crystals, 1958 [3]. Procedures are described in the Standards on Piezoelectric Crystals, 1957 [2], and in the literature [6]–[8]. The transmission method is used for determination of f_m, the frequency at minimum impedance of the sample. In addition to this measurement, the present Standard also specifies the measurement of the frequency at maximum impedance f_n. A simplification of the transmission network in the 1957 Standard (Fig. 4) may be used in view of the range of parameters found in the ceramics. This simplified circuit is shown in Fig. 1. The signal generator should have an output impedance lower than the minimum impedance of the test specimen. The terminating resistance (R_T) should also be lower than the minimum impedance of the test specimen. In determining the frequency of maximum impedance a higher terminating resistance may be used. The frequency at maximum impedance can be determined accurately only if the harmonic content of the signal generator is relatively low. The effective shunt or

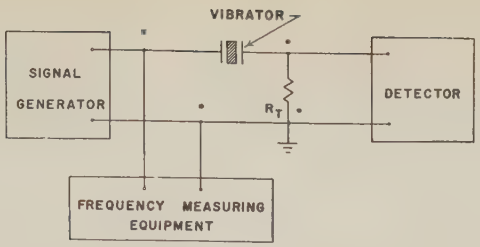


Fig. 1—Transmission network for determination of f_m and f_n of piezoelectric ceramic vibrator.

fringing capacitance across the test specimen should be very low compared to the capacitance of the test specimen. This is generally no problem with high-dielectric-constant ceramics, except in the determination of the longitudinal coupling factor k_{33} for elongated cylinders. In this case it is advisable to use double shielding, whereby the effective shunt capacitance is placed across the signal generator so that current through this shunt capacitance does not pass through the series resistance. The shunt capacitance affects the determination of the frequency at maximum impedance f_n, but not the frequency at minimum impedance f_m, and its effect is such that the apparent maximum-impedance frequency is lowered. The shielding should, therefore, be adjusted for the highest maximum-impedance frequency.

2.1.2 Applicable Approximation: The equations which follow contain the parallel resonance frequency f_p and the series resonance frequency f_s. Another characteristic pair for a resonance range are the frequencies of zero reactance, f_a (antiresonance) and f_r (resonance). The frequency differences are in the order

$$(f_n - f_m) > (f_p - f_s) > (f_a - f_r).$$

With piezoelectric ceramics of high coupling factor and reasonably high mechanical and dielectric quality factors, these three frequency differences are nearly equal. In the presence of high mechanical losses, however, $(f_n - f_m)$ cannot be used directly in calculating coupling factors, and a closer approximation for $(f_p - f_s)$ in terms of the measured frequency difference $(f_n - f_m)$ must be used as follows:

$$\Delta f = (f_p - f_s) \sim \frac{f_n - f_m}{\sqrt{1 + \frac{4}{M^2}}}, \qquad (2)$$

where the figure of merit M is given by

$$M = \frac{1}{2\pi f_s R_1 C_0} \approx \frac{1}{2\pi f_m (C_0 + C_1)\,|Z|_{\min}}. \qquad (3)$$

Measurements indicate that the assumptions on which these relations depend are valid in rough approximation. The sum $(C_0 + C_1)$ is the static capacitance which may be measured at a frequency well below the fundamental resonance, for instance at 1 kc.

The error made in $(f_p - f_s)$ by use of the approximate equations (2) and (3) is less than 1 per cent if $M^2(f_p - f_s)/f_s > 100$.

2.1.3 Measurements on Disks in Radial Vibration: One of the fundamental measurements for piezoelectric ceramics is that of determining the planar coupling factor k_p. The term "planar" is used because the stress is two-dimensional (plane) isotropic. The planar coupling factor is related to the conventional piezoelectric and elastic constants by

$$k_p^2 = \frac{2d_{31}^2}{\epsilon_{33}^T(s_{11}^E + s_{12}^E)} = \left(\frac{2}{1 - \sigma^E}\right) k_{31}^2. \qquad (4)$$

The cross contraction or Poisson's ratio σ^E is the ratio $-s_{12}^E/s_{11}^E$, and k_{31} is termed the transverse coupling factor. Poisson's ratio lies between 0.28 and 0.32 for barium titanate, modified barium titanate, and lead titanate zirconate ceramics. For any piezoelectric ceramic, its value can be accurately determined from resonances of square plates as shown in the Standard on Piezoelectric Crystals, 1958 [3], Section 2.7.2.

The planar coupling factor is obtained from the fundamental mode f_p and f_s of a thin disc with faces perpendicular to the Z axis as follows [9]:

$$\frac{k_p^2}{1 - k_p^2} = \frac{(1-\sigma^E)J_1[\eta_1(1+\Delta f/f_s)] - \eta_1(1+\Delta f/f_s)J_0[\eta_1(1+\Delta f/f_s)]}{(1+\sigma^E)J_1[\eta_1(1+\Delta f/f_s)]}, \qquad (5)$$

where

J_0 = Bessel function of first kind and zero order,

J_1 = Bessel function of first kind and first order,

η_1 = lowest positive root of $(1+\sigma^E)J_1(\eta) = \eta J_0(\eta)$. (For $\sigma^E = 0.31$, $\eta_1 = 2.05$).

This relationship is plotted in Fig. 2, where k_p is shown as a function of $\Delta f/f_s$. The curve is drawn for $\sigma^E = 0.31$, but the deviation for σ^E between 0.27 and 0.35 is too small to show on the graph.

Eq. (5) was derived for an infinitely thin disk. For disks of finite thickness, the value for k_p obtained from (5) is higher than the true k_p of the material. For typical ceramics, the error is less than 1 per cent for a thickness to diameter ratio t/d smaller than 0.1. Rayleigh-type corrections may be made [10], and characteristic corrections are shown in Fig. 3. Even though corrections up to 10 per cent are shown, it is recommended that corrections over 3 per cent be considered only approximate. It may be readily inferred from Fig. 3 that the correction increases rapidly with increasing t/d, and that it is higher for compositions with low piezoelectric coupling and high $|d_{33}/d_{31}|$.

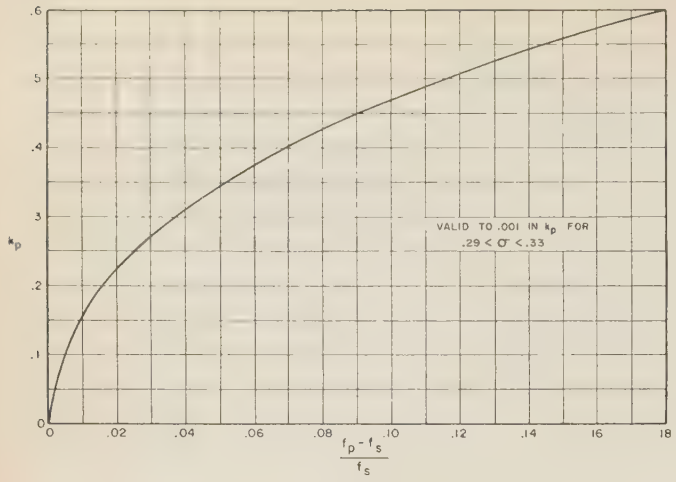


Fig. 2—Planar coupling factor of thin disk.

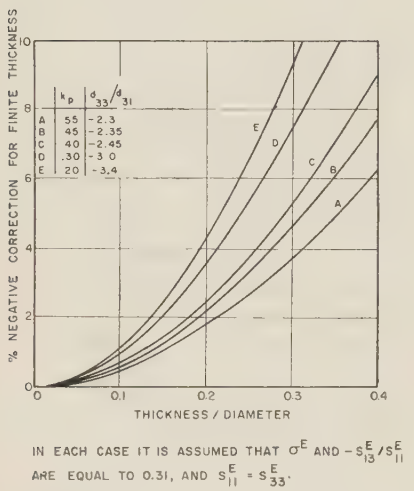


Fig. 3—Rayleigh correction for disk of finite thickness (applied to ordinate of Fig. 2 to obtain true k_p).

From the measured planar coupling factor, free dielectric constant, fundamental planar resonance frequency, and the density of a disk, the piezoelectric constants d_{31} and g_{31} may be calculated, as follows:

$$k_{31}^2 = \left(\frac{1 - \sigma^E}{2}\right) k_p^2,$$

$$\frac{1}{s_{11}^E} = \frac{\pi^2 d^2 f_s^2 (1 - \sigma^{E^2})\rho}{\eta_1^2},$$

$$d_{31} = k_{31}\sqrt{\epsilon_{33}^T s_{11}^E},$$

and

$$g_{31} = d_{31}/\epsilon_{33}^T. \tag{6}$$

2.1.4 Measurements on Bars and Thin Cylinders: The transverse coupling factor k_{31} may be determined according to (7) directly from the fundamental f_p and f_s of bars with thickness along the poling axis:

$$\frac{k_{31}^2}{1 - k_{31}^2} = \frac{\pi}{2}\frac{f_p}{f_s}\tan\left(\frac{\pi}{2}\frac{\Delta f}{f_s}\right). \tag{7}$$

The bars should have $(l/t)^2$ and $(l/w)^2$ both greater than 10. Combination of (7) with the first of (6) gives Poisson's ratio σ^E, provided that the bar and disk are in the same condition of polarization.

The longitudinal coupling factor k_{33} may be determined from the fundamental f_p and f_s of thin cylinders or bars electroded at the ends. This is generally most conveniently done with square or circular cross section, and the length should be at least two and one-half times the largest lateral dimension. The following relations then hold:

$$k_{33}^2 = \frac{\pi}{2}\frac{f_s}{f_p}\tan\frac{\pi}{2}\frac{\Delta f}{f_p},$$

$$\frac{1}{s_{33}^D} = 4\rho f_p^2 l^2,$$

$$s_{33}^E = s_{33}^D/(1 - k_{33}^2),$$

$$d_{33} = k_{33}\sqrt{\epsilon_{33}^T s_{33}^E},$$

and

$$g_{33} = d_{33}/\epsilon_{33}^T. \tag{8}$$

2.1.5 Measurements Relating to Shear Modes: The shear piezoelectric coupling factor k_{15} is preferably determined from dielectric measurements. A bar of square or rectangular cross section with length approximately twice the largest lateral dimension is poled along the length. Then another pair of faces is electroded. The shear deformation then occurs in the plane containing both the poling and signal fields. The free permittivity ϵ_{11}^T is obtained by a measurement of the capacitance at a frequency well below the fundamental resonance, which is determined by the dimension along the direction of the signal field. The clamped permittivity ϵ_{11}^S is determined by measurement of the capacitance at a frequency above any pronounced overtone of the thickness shear mode. The coupling factor is determined from the relation

$$\epsilon_{11}^S = (1 - k_{15}^2)\epsilon_{11}^T, \tag{9}$$

where

$$k_{15}^2 = \frac{d_{15}^2}{\epsilon_{11}^T s_{55}^E}.$$

Many ferroelectric ceramics have slowly decreasing capacitance with increasing frequency. The capacitance should therefore be measured over a frequency range below the fundamental resonance and above any pronounced overtones. Each curve may then be extrapolated to the resonance frequency.

The elastic compliance s_{55}^D may be determined from the successive parallel resonance frequencies f_{p_i} at a series of overtones of the thickness shear mode divided by the respective integers according to (10):

$$\frac{1}{s_{55}^D} = 4\rho(f_{pi}t/i)^2; \qquad i = 1, 3, 5, \cdots. \tag{10}$$

Third, fifth, and seventh overtones should in this case deviate from a harmonic sequence by less than about 1 per cent, and may be averaged. The piezoelectric strain constants g_{15} and d_{15} are then given by

$$s_{55}^E = s_{55}^D/(1 - k_{15}^2),$$
$$d_{15} = k_{15}\sqrt{\epsilon_{11}^T s_{55}^E}, \tag{11}$$

and

$$g_{15} = d_{15}/\epsilon_{11}^T.$$

2.1.6 Measurements on Plates in Thickness Vibration: The elastic stiffness c_{33}^D may be determined by measurement of f_{p_i} at overtones of the thickness extensional mode of a thin plate with faces perpendicular to the Z axis:

$$c_{33}^D = 4\rho(f_{pi}t/i)^2. \tag{12}$$

A measurement of the laterally-clamped thickness coupling factor k_t is not recommended in general, since the fundamental thickness extensional resonance of thin plates is not always free from unwanted resonances. The coupling factor k_t is directly related to the piezoelectric stress constant h_{33} rather than the strain constant d_{33}. For a very thin plate with infinite lateral dimensions, the square of the coupling factor is

$$k_t^2 = \frac{\pi}{2}\frac{f_s}{f_p}\tan\left(\frac{\pi}{2}\frac{\Delta f}{f_p}\right), \tag{13}$$

where

$$k_t^2 = h_{33}^2\epsilon_{33}^S/c_{33}^D.$$

Corrections for finite lateral dimensions have been not calculated, but they may be fairly high, since finite dimensions require a set of boundary conditions at the extreme edges.

The elastic stiffness c_{33}^E is given by

$$c_{33}^E = c_{33}^D(1 - k_t^2). \tag{14}$$

The clamped permittivity ϵ_{33}^S may be obtained from measurement of the capacitance of a thin plate in a frequency range above the fundamental thickness resonance and all pronounced overtones, and extrapolation to the operating frequency. In view of the substantial frequency dependence of ϵ_{33}^S in the megacycle range, a calculation from ϵ_{33}^T and piezoelectric data is preferred (see Table I).

2.1.7 Measurement of Q: The mechanical quality factor[3] Q is obtained from determination of the minimum impedance $|Z_m|$ at the fundamental resonance. This measurement may be accomplished by substitution of a variable resistance for the test specimen and adjustment for a current equal to the current through the specimen at f_m. For this measurement it is important that the specimen be held only at nodal points, although this is not nearly so critical as for high-Q crystals such as quartz. Q is given by the relation

$$\frac{1}{Q} = 2\pi f_s|Z_m|(C_0 + C_1)\left(\frac{f_p^2 - f_s^2}{f_p^2}\right)$$
$$\sim 4\pi\Delta f|Z_m|(C_0 + C_1). \tag{15}$$

The approximate expression leads to an error in Q of about 6.5 per cent for $\Delta f/f_s = 0.05$, 13 per cent for $\Delta f/f_s = 0.10$, and 23 per cent for $\Delta f/f_s = 0.20$. In each case the approximate expression gives a value which is too low.

Q is not independent of configuration or mode of vibration. It is generally lower for shear than for dilatational modes.

2.2 Static and Quasi-Static Methods

Piezoelectric strain constants may be measured under static or quasi-static conditions with reasonable accuracy, although the precision is inferior to that obtained with the resonance method. Both quasi-static and static piezoelectric measurements are described in the literature [6]. The relations used are

$$d_{31} = \left(\frac{\partial D_3}{\partial T_1}\right)_E = \left(\frac{\partial S_1}{\partial E_3}\right)_T,$$

and

$$d_{33} = \left(\frac{\partial D_3}{\partial T_3}\right)_E = \left(\frac{\partial S_3}{\partial E_3}\right)_T. \tag{16}$$

The high values of the strain constants d_{31} and d_{33} and good insulation resistance of typical piezoelectric ceramics at room temperature make direct measurement of response to static stress convenient. A recommended procedure is shock-free lifting of a previously applied weight from the specimen. The generated charge flows into a low-loss capacitor, whose capacitance is at least 10 and preferably 100 times that of the specimen. Voltage is measured by a tube electrometer; it is typically in the 0.1- to 10-volt range. Total generated charge is then calculated as the product of observed voltage and the sum of shunt capacitance and static specimen capacitance.

[3] The synbol Q in this and the preceding Standards on Piezoelectric Crystals always designates the mechanical quality factor (ratio of strain in-phase to strain out-of-phase with stress), which becomes observable electrically through the piezoelectric effect. The dielectric Q factor found in the capacitor literature is the reciprocal of the dissipation factor introduced in (19).

The hydrostatic response can be measured at 10 to 100 cps as described in the literature [6]. The hydrostatic strain constant d_h is related to d_{33} and d_{31} as follows:

$$d_h = 2d_{31} + d_{33}. \tag{17}$$

This provides a convenient means for routine measurement of both d_{33} and d_{31} on the same test specimen. The latter may be determined from resonance measurements on a thin disk, and the former may be calculated using d_{31} and d_h and (17). This involves combining measurements at widely differing frequencies. Experience with $BaTiO_3$ has not shown any frequency dependence of piezoelectric low-signal coefficients over a very wide range, at least from 100 cps to 100 kc [11].

3. Response to Large Signals

As previously noted, piezoelectric ceramics and ferroelectric crystals show linear relations between components of stress and strain on the one hand and electric field and displacement on the other only over limited ranges of the input signal. The limit of linear behavior is related to the coercive force and varies widely with ceramic composition.

3.1 Condition of Electric Drive

A direct measurement of mechanical strain as a function of driving electric field may be obtained on an oscilloscope using a displacement meter [6] or strain gauges. Of even greater practical importance for designers of piezoelectric ceramic transducers are dielectric losses resulting from dielectric hysteresis. This is due to the fact that in itself nonlinearity of the strain-field relationship results only in harmonic distortion of the acoustic power output, whereas a sharp increase in dielectric losses at high field amplitudes results in lowered acoustic efficiency and increased generation of internal heat which may lead to depoling.

For transducer applications the desired effect is mechanical strain; internal heat generation is the undesired effect. For quasi-static conditions, the strain is given by

$$S_3 = d_{33}E_3$$

or

$$S_1 = d_{31}E_3. \tag{18}$$

The power lost to internal heat is given by

$$H = 2\pi f \epsilon D E^2. \tag{19}$$

It is necessary to measure both the permittivity ϵ and the dissipation factor D as functions of applied field E, since both are field-dependent. It is suggested that the performance of ferroelectric ceramics under high electric drive be specified by a plot of internally generated heat per cycle as a function of strain amplitude. The internally generated heat per unit volume per cycle is given by $2\pi\epsilon DE^2$, and the strain is given by (18). The nonlinearity of the strain-field relationship may be disregarded. With ceramic barium titanate, for instance, the strain-field relationship is linear up to fields of 6000 to 8000 volts/cm; at this field level the dielectric dissipation factor has already increased from less than 0.01 to over 0.10.

Measurements of permittivity and dissipation factor as function of electric driving field should be made with the specimen immersed in a stirred oil bath. Otherwise, the generation of internal heat leads to a temperature rise dependent upon the configuration of the test specimen.

Dependence of mechanical losses on strain amplitude may be obtained from the series resonance resistance R_1 of an unloaded vibrator, or from the temperature rise of such a vibrator. Mechanical as well as dielectric losses in the piezoelectric transducer material detract from the efficiency of a loaded transducer. If all other factors are known this may allow a determination of the mechanical loss factor. In the case of well-loaded acoustic transducers it has been assumed that internal dielectric losses are considerably greater than internal mechanical losses.

High ac electric fields depolarize poled ferroelectric ceramics. The degree of depolarization is a function of the applied ac field and temperature. For typical barium titanate, at room temperature, depolarization may become noticeable at 400 volts/mm rms and be substantially complete at 800 volts/mm rms. The depolarization test should be made in an oil bath so that the temperature may be controlled . Test specimens should be subjected to progressively higher electric driving fields, with the relative frequency separation $(f_p - f_s)/f_s$ measured after each exposure. The frequency of the electric driving field should be such that internal heating is not too great; 60 cps is convenient.

3.2 Condition of Mechanical Drive

For some applications the nonlinear response to high mechanical stress is utilized. In the linear range the charge density and field caused by an axial stress T_3 are

$$D_3 = d_{33}T_3$$

and

$$E_3 = g_{33}T_3. \tag{20}$$

The generated electric charge density increases more than proportionally to applied stress over a pressure range, typically 20 to 100 million newton/meter^2 for $BaTiO_3$, and then approaches a saturation value equal to the total electric polarization of the poled ceramic, about 8 micro coulomb/cm^2 for barium titanate. After

stressing near to saturation, the electric polarization is not recovered upon release of the stress.

Test specimens for study of these effects should have the largest lateral dimension not more than twice the length to avoid lateral constraint. The stress should be applied as nearly perpendicular to the specimen faces as possible, using a mechanical or hydraulic press. The released charges should be collected on a large capacitance connected in parallel with the test specimen.

It has been shown that for a given ceramic composition the total ferroelectric charge of a specimen is approximately proportional to its piezoelectric coupling coefficient. Once a relationship between, for instance, k_p and total ferroelectric charge has been established for a ceramic composition, it is necessary to measure only k_p for other specimens of the same composition in order to determine suitability for an application utilizing the total ferroelectric charge.

The open-circuit field remains a nearly linear function of stress to far higher stress levels than does the electric displacement, and no permanent loss of polarization occurs. For measurements of open-circuit voltage a very-high-impedance electrometer must be used.

4. Pyroelectric Effects

The magnitude of ferroelectric polarization is temperature dependent. Over a range of temperature below the Curie point and excluding other phase transitions the temperature variation of this ferroelectric polarization is reversible and may be defined by a pyroelectric coefficient $(\partial P/\partial\theta)_T$. As noted, the measurement is normally at constant stress, and hence includes both the primary and secondary effects [12].

A convenient measurement of the integrated pyroelectric effect can be made by suddenly immersing the test specimen in heated oil and collecting the electric charges on a capacitance connected in parallel. This method is, however, satisfactory only so long as the time constant of the test specimen and parallel capacitance is high enough so that only negligible decay occurs during the time required for domain realignment and the relief of thermal stresses. A low-impedance circuit method is, therefore, recommended. A fairly sensitive galvanometer is connected across the test specimen, which is slowly heated. Both pyroelectric current and specimen temperature are recorded as function of time. The ratio of current per unit area to $\partial\theta/\partial t$ gives directly the pyroelectric coefficient. An integration of the current-time curve over specific temperature intervals is recommended to obtain the electric moment as a function of temperature.

5. Aging

The parameters of ferroelectric ceramics change with time after major disturbances, such as temporary heating to high temperature for electroding, or the poling process. These changes are in the direction of decreasing dielectric and piezoelectric constants and mechanical compliance, and, hence, increase in frequency constant. The aging rate may be expressed in the form

$$\frac{1}{y(1)}\frac{dy}{dt} = ct^{-1}, \tag{21}$$

where y is the parameter under consideration, $y(1)$ is its value at unit time (such as one day) after the disturbance, and c is a coefficient characteristic of the material and parameter involved. With c independent of time, (21) can be integrated to

$$\frac{y - y(1)}{y(1)} = c \ln t = c' \log_{10} t. \tag{22}$$

The latter relation is the basis for specifying "aging per decade" with typical values of c' for resonance frequency constants in the range of 0.05 per cent to 1.5 per cent, and for piezoelectric coupling factors and dielectric constants in the range from -0.5 per cent to -5 per cent. Even higher negative aging rates are found for the dissipation factor, and higher positive rates for Q.

The coefficient c in (21) itself varies slowly with time, usually in a decreasing sense of its absolute value, and therefore (22) is only an approximation. For a typical barium titanate ceramic, the frequency constant was found to increase by 0.54 per cent from 1 day to 10 days after poling, by 0.51 per cent from 10 days to 100 days, and by 0.42 per cent from 100 days to 1000 days. The decade or decades to be used for specifying c' should therefore be stated.

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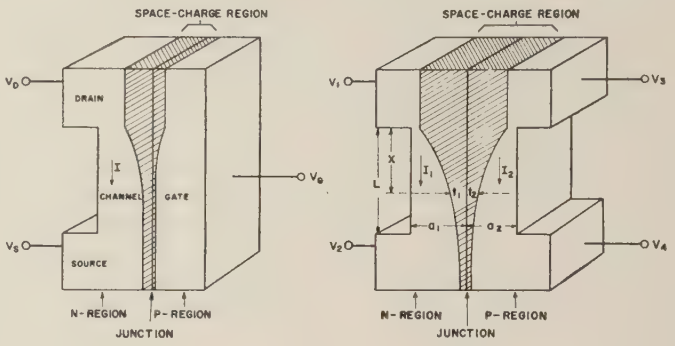
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The Field-Effect Tetrode*

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Summary—**The new device described here consists basically of a thin *N* region adjacent to a comparably thin *P* region. Two contacts are made to the *N* side and two to the *P* side so that currents can be passed through each thin region parallel to the single junction of the device. The two currents do not mix because reverse bias is maintained on the junction. A current in either side affects the resistance of the other side, and hence the current in the other side, through the medium of the depletion layer; this mutual interaction of currents gives the device its unique properties. The field-effect tetrode has applications as a gyrator and isolator. In a two-terminal connection it exhibits voltage-controlled negative resistance. Also, it can be applied as a truly linear, yet electronically variable, resistor. Equations are developed for its behavior in these applications and experimental results are discussed. In the models to date, the thin regions were shaped by rather tedious mechanical and chemical procedures. Epitaxial film techniques may be well adapted to its fabrication in the future.**



(a) (b)

Fig. 1—Field-effect devices. (a) Field-effect transistor. (b) Field-effect tetrode.

I. Introduction

THE field-effect tetrode[1] embodies the principles of field effect in a new type of semiconductor device. The structure consists of two independently terminated conducting channels so disposed that the conductance of each is modulated along its length by the voltage conditions in the other. Conceptually, the field-effect tetrode may be likened to a field-effect transistor[2] in which the gate is replaced by a second channel and each of the channels acts as a gate for the other.

The geometry is shown schematically and is compared to a field-effect transistor in Fig. 1. Voltages may be applied to all of the four terminals, and subject only to the restriction that reverse bias should obtain, these voltages may be mutually independent. The pattern of depletion-layer penetration and the resulting conductances of the two channels are uniquely determined by the voltage differences $V_1 - V_3$ and $V_2 - V_4$ appearing across the junction at the two ends of the channels, and are independent of the voltage drop along the channels $V_1 - V_2$ and $V_3 - V_4$.

In addition to its implications as an amplifier, the field-effect tetrode can be adapted to a variety of other circuit functions. These include impedance inversion, undistorted large-signal modulation and, in a two-terminal configuration, voltage-controlled negative resistance.

Units have been made at Bell Laboratories from silicon crystals with diffused junctions, the required geometry being achieved by grinding and etching. Measurements on models have confirmed some of the predicted device behavior.

II. Current-Voltage Equations

Associated with a field-effect transistor is the "pinch-off" voltage.[2] This is the voltage which, if applied as a reverse bias across the junction, would cause the depletion layer to extend completely across the channel. A field-effect tetrode may be considered to have two pinch-off voltages since there are two channels and the voltages required for the depletion layer to traverse them need not be the same. The following derivation of the current-voltage equation is undertaken for the case where they are exactly equal.

General equations, where no restrictions are put on the pinch-off voltages, are developed in Appendix II. These equations have a transcendental term and cannot be solved explicitly. However, approximate solutions are derived for the case where the pinch-off voltages are nearly equal. For most practical applications it is likely that interest will center around devices whose pinch-off voltages are not widely different.

A number of simplifying approximations will be made in developing the current-voltage equations. Among them is the assumption that the impurities in each region are uniformly distributed. In a diffused structure this is, of course, not so; and while this leads to differences in detail, it does not basically alter the behavior described by the equation.

A one-dimensional model is used, assuming that the potential at any point along the channel is independent of its location with respect to the depletion layer and the surface.

* Received by the IRE, January 30, 1961.
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Another assumption is that there are no abrupt changes in the depletion-layer thickness along the channel. This condition is probably not seriously violated except when the bias voltages are close to the pinch-off values. The built-in voltage has been ignored in the analysis. It can be accommodated after the fact by suitably adjusting the numbers used for the bias voltages. It is assumed that the donors and acceptors are completely ionized and that the depletion layer has a sharp boundary. Finally, no attempt has been made to take into account limiting velocities in high fields, and this also may lead to some discrepancy as the pinch-off voltage is approached.

A. Symmetrical Case

Consider the structure symbolized in Fig. 1. Let the applied voltages at the terminals be V_1, V_2, V_3, V_4 as shown. The restrictions on these voltages are:

1) V_1 positive with respect to V_3, and V_2 positive with respect to V_4, so that all parts of the junction will be reverse biased.
2) $V_1 - V_3 \leq W_p$ and $V_2 - V_4 \leq W_p$, where W_p is the potential difference across the junction which will cause at least one side to pinch-off.

The thicknesses of the depletion layers are shown in Appendix I to be given by

$$t_1^2 = \frac{2\kappa\epsilon_0}{q} \frac{P}{N(P+N)} (v_1 - v_2) \tag{1}$$

$$t_2^2 = \frac{2\kappa\epsilon_0}{q} \frac{N}{P(P+N)} (v_1 - v_2), \tag{2}$$

where v_1 and v_2 are the potentials in the N and P channels, respectively, at some value of x; N is the net donor density in channel 1 and P is the net acceptor density in channel 2. The pinch-off voltage in the N channel W_{1p} is defined as the value of $v_1 - v_2$ for which $t_1 = a_1$.

$$W_{1P} = \frac{qNa_1^2(P+N)}{2\kappa\epsilon_0 P}. \tag{3}$$

Similarly, the pinch-off voltage in the P channel is defined by

$$W_{2P} = \frac{qPa_2^2(P+N)}{2\kappa\epsilon_0 N}. \tag{4}$$

In the symmetrical case,

$$W_{1P} = W_{2P} = W_P \tag{5}$$

and

$$a_1 N = a_2 P = \sqrt{\frac{2\kappa\epsilon_0}{q}} \sqrt{\frac{PN}{P+N}} W_P^{1/2}. \tag{6}$$

Also, at any point along the channels,

$$t_1 N = t_2 P = \sqrt{\frac{2\kappa\epsilon_0}{q}} \sqrt{\frac{PN}{P+N}} (v_1 - v_2)^{1/2} \tag{7}$$

and

$$\frac{t_1}{a_1} = \frac{t_2}{a_2} = \frac{(v_1 - v_2)^{1/2}}{(W_P)^{1/2}}. \tag{8}$$

At any point x along the channels, the resistances of the elements of length are

$$dR_1 = \frac{dx}{q\mu_1 NZ(a_1 - t_1)} = \frac{dx}{G_1 L\left(1 - \frac{t_1}{a_1}\right)} \tag{9}$$

and

$$dR_2 = \frac{dx}{q\mu_2 PZ(a_2 - t_2)} = \frac{dx}{G_2 L\left(1 - \frac{t_2}{a_2}\right)}, \tag{10}$$

where μ_1 and μ_2 are the N and P carrier mobilities, respectively, L is the channel length, Z is the width (into the paper) of the channel and G_1 and G_2 are the initial conductances of the respective channels.

The currents in the channels are

$$I_1 = -\frac{dv_1}{dR_1} = -G_1 L\left(1 - \frac{t_1}{a_1}\right)\frac{dv_1}{dx} \tag{11}$$

and

$$I_2 = -\frac{dv_2}{dR_2} = -G_2 L\left(1 - \frac{t_2}{a_2}\right)\frac{dv_2}{dx}. \tag{12}$$

In the symmetrical case, from (8)

$$I_1 dx = -G_1 L\left[1 - \frac{(v_1 - v_2)^{1/2}}{(W_P)^{1/2}}\right] dv_1 \tag{13}$$

$$I_2 dx = -G_2 L\left[1 - \frac{(v_1 - v_2)^{1/2}}{(W_P)^{1/2}}\right] dv_2. \tag{14}$$

These equations can be solved simultaneously for the two currents. For the first solution, (13) is divided by (14)

$$\frac{I_1}{G_1} dv_2 = \frac{I_2}{G_2} dv_1$$

and integrated

$$\frac{I_1}{G_1}\int_{V_3}^{V_4} dv_2 = \frac{I_2}{G_2}\int_{V_1}^{V_2} dv_1$$

$$\frac{I_1}{G_1}(V_3 - V_4) = \frac{I_2}{G_2}(V_1 - V_2). \tag{15}$$

For the second solution,

$$dv_1 - dv_2 = d(v_1 - v_2) = -\frac{\frac{I_1}{G_1} - \frac{I_2}{G_2}}{L\left[1 - \frac{(v_1 - v_2)^{1/2}}{(W_P)^{1/2}}\right]} dx.$$

Integrating

$$\int_{V_1 - V_3}^{V_2 - V_4} \left[1 - \frac{(v_1 - v_2)^{1/2}}{(W_P)^{1/2}}\right] d(v_1 - v_2) = -\frac{\frac{I_1}{G_1} - \frac{I_2}{G_2}}{L} \int_0^L dx$$

$$\frac{I_1}{G_1} - \frac{I_2}{G_2} = [(V_1 - V_3) - (V_2 - V_4)] - \frac{2}{3W_P^{1/2}}[(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}]. \quad (16)$$

From (15) and (16), the current equations are found to be

$$I_1 = G_1(V_1 - V_2) \cdot \left[1 - \frac{2}{3W_P^{1/2}} \frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right] \quad (17)$$

$$I_2 = G_2(V_3 - V_4) \cdot \left[1 - \frac{2}{3W_P^{1/2}} \frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right]. \quad (18)$$

It will be noted that the first term in each equation is simply Ohm's law for that channel, and the second term describes the modulation of conductance in terms of the voltage differences $V_1 - V_3$ and $V_2 - V_4$ appearing across the two ends of the device.

B. Comparison with Field-Effect Transistor

It can be shown that the field-effect transistor[2] is a limiting case of the field-effect tetrode. It is apparent that if no current flows in one of the channels, that channel will behave as a field-effect transistor gate. If, in Fig. 1, we let

$$V_3 = V_4 \equiv V_G$$

$$V_1 \equiv V_D$$

and

$$V_2 \equiv V_S,$$

(17) will reduce to

$$I_1 = J(V_D - V_G) - J(V_S - V_G), \quad (19)$$

where the function $J(\lambda)$ is defined by

$$J(\lambda) = G_1\lambda\left\{1 - \frac{2\lambda^{1/2}}{3W_P^{1/2}}\right\}. \quad (20)$$

These are the equations for a field-effect transistor.

Strictly speaking, (17) applies only to symmetrical structures. However, (20) can also be derived from (90), Appendix II, in a similar manner and without any restriction on the symmetry of the unit.

The field-effect tetrode bears a superficial resemblance to a pair of complementary field-effect transistors connected back to back. It is of interest to explore whether the behavior of two field-effect transistors, interconnected as shown in Fig. 2, would be equivalent to that of the tetrode. In order that the equations we derive can be compared directly to (17) and (18) for the tetrode, we will restrict ourselves to the case where both units have the same value of pinch-off voltage.

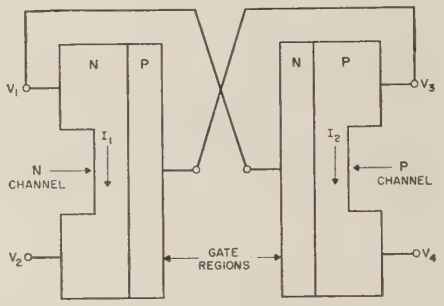


Fig. 2—Complementary field-effect transistors in back-to-back configuration.

Consider first the unit on the left with the P-type gate and N-type channel. Noting that V_1 corresponds to the drain and V_2 to the source, (19) becomes

$$I_1 = J_1(V_1 - V_3) - J_1(V_2 - V_3), \quad (21)$$

where J_1 is defined as in (20). Similarly, in the unit on the right, with the N-type gate and P-type channel, the current can be shown to be

$$I_2 = J_2(V_3 - V_1) - J_2(V_4 - V_1), \quad (22)$$

where

$$J_2 = G_2\lambda\left\{1 - \frac{2\lambda^{1/2}}{3W_P^{1/2}}\right\}. \quad (23)$$

To facilitate comparison with (17) and (18), (21) and (22) can be written in a similar form. They become

$$I_1 = G_1(V_1 - V_2) \cdot \left[1 - \frac{2}{3W_P^{1/2}} \frac{(V_1 - V_3)^{3/2} - (V_2 - V_3)^{3/2}}{(V_1 - V_3) - (V_2 - V_3)}\right] \quad (24)$$

$$I_2 = G_2(V_3 - V_4)$$

$$\cdot\left[1 - \frac{2}{3W_P^{1/2}} \frac{(V_1 - V_3)^{3/2} - (V_1 - V_4)^{3/2}}{(V_1 - V_3) - (V_1 - V_4)}\right]. \quad (25)$$

We note that the currents in each channel of the tetrode are a function of all four applied voltages, whereas each of the currents in the two field-effect transistors depends on three applied voltages only. There is a symmetry in the tetrode (indicated by the fact that the expressions in brackets are identical) which is lacking in the field-effect transistor. The importance of this factor becomes evident in the discussion of the electronically variable resistor, whose performance cannot be duplicated with field-effect transistors

The other applications discussed in this paper could be effected with complementary field-effect transistors; only the quantitative considerations would be different.

III. Voltage-Controlled Negative Resistance

If terminals 2 and 3 of the field-effect tetrode [Fig. 1(b)] are interconnected, the characteristics measured between terminals 1 and 4 are of some interest. In the following analysis, we will set terminal 4 at reference zero and examine the current as a function of the voltage applied at terminal 1. For the symmetrical case, (17) and (18) reduce to

$$I_1 \equiv I = G_1(V_1 - V_2)$$

$$\cdot\left[1 - \frac{2}{3W_P^{1/2}} \frac{(V_1 - V_2)^{3/2} - V_2^{3/2}}{(V_1 - V_2) - V_2}\right] \quad (26)$$

$$I_2 = I = G_2V_2\left[1 - \frac{2}{3W_P^{1/2}} \frac{(V_1 - V_2)^{3/2} - V_2^{3/2}}{(V_1 - V_2) - V_2}\right]. \quad (27)$$

We can solve these equations, eliminating V_2 and expressing the current as a function of V_1. One way to proceed is to divide (26) by (27) and establish that

$$V_2 = \frac{G_1}{G_1 + G_2} V_1. \quad (28)$$

Noting from (6) that a_1N and a_2P are equal, it follows that

$$\frac{G_1}{G_2} = \frac{\mu_1}{\mu_2} \equiv b. \quad (29)$$

From (28) and (29),

$$V_2 = \frac{b}{b + 1} V_1 \quad (30)$$

and

$$(V_1 - V_2) = \frac{1}{b + 1} V_1. \quad (31)$$

Inserting these values in (26), we obtain

$$I = \frac{G_1}{b + 1} V_1\left\{1 - \frac{2}{3}\left(\frac{V_1}{W_P}\right)^{1/2} \frac{b^{3/2} - 1}{(b + 1)^{1/2}(b - 1)}\right\}. \quad (32)$$

It is to be noted that pinch-off does not occur when V_1 equals W_p, but rather when the voltage across the junction, $(V_1 - V_2)$ or V_2, first reaches that value. In a real semiconductor $\mu_1 > \mu_2$ and $b > 1$. Eqs. (30) and (31) show that in a symmetrical unit V_2 is always greater than $V_1 - V_2$; thus pinch-off occurs when V_2 reaches the value W_P. The corresponding value of applied voltage V_P is

$$V_P = \frac{b + 1}{b} W_P. \quad (33)$$

We can rewrite (32) in terms of the applied voltage which will produce pinch-off:

$$I = \frac{1}{b} G_1W_P\left(\frac{V_1}{V_P}\right)$$

$$\cdot\left\{1 - \frac{2}{3}\left(\frac{V_1}{V_P}\right)^{1/2} \frac{b + b^{1/2} + 1}{b + b^{1/2}}\right\}. \quad (34)$$

At pinch-off the current becomes

$$I_P = \frac{1}{b} G_1W_P\left\{1 - \frac{2}{3} \frac{b + b^{1/2} + 1}{b + b^{1/2}}\right\}. \quad (35)$$

We can now normalize (34) in terms of the pinch-off current:

$$\frac{I}{I_P} = \frac{1 - \frac{2}{3} \frac{b + b^{1/2} + 1}{b + b^{1/2}}\left(\frac{V_1}{V_P}\right)^{1/2}}{1 - \frac{2}{3} \frac{b + b^{1/2} + 1}{b + b^{1/2}}}\left(\frac{V_1}{V_P}\right). \quad (36)$$

For silicon, assuming $b = 3.0$, (36) becomes

$$\frac{I}{I_P} = 5.25\left(\frac{V_1}{V_P}\right) - 4.25\left(\frac{V_1}{V_P}\right)^{3/2}. \quad (37)$$

This equation is plotted in Fig. 3, and Fig. 4 shows a photograph of the V-I characteristic of a laboratory unit.

The type of negative resistance displayed by the field-effect tetrode bears a resemblance to that of the Esaki[3] diode. However, there are two important differences: first, the impedance levels of the field-effect tetrode are very much higher, from several hundred to several thousand ohms; second, the tetrode is limited in speed by the time constant associated with the junction capacitance and channel resistance.

[3] L. Esaki, "New phenomenon in narrow germanium P-N junctions," *Phys. Rev.*, vol. 109; pp. 603–604; January 15, 1958.

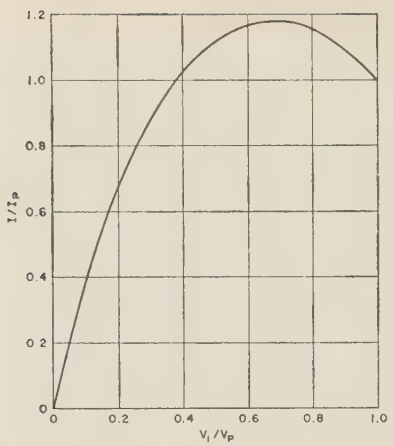


Fig. 3—*V-I* characteristic of field-effect tetrode in negative resistance configuration.

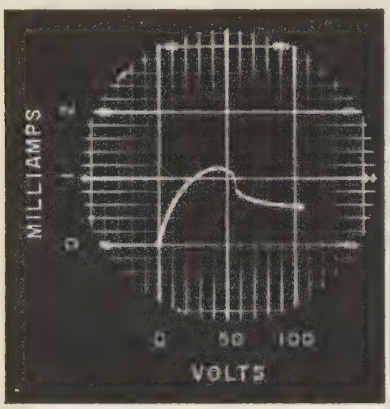


Fig. 4—Voltage-controlled negative resistance in laboratory model of field-effect tetrode.

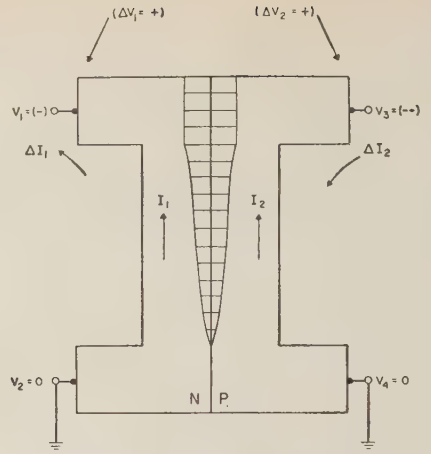


Fig. 5—Bias arrangement for admittances of opposite sign.

IV. Gyrator

A. Basic Nonreciprocal Properties

The field-effect tetrode, treated as a four-terminal network for the case of small ac signals, exhibits nonreciprocity in all except a special class of bias conditions which are discussed in Section V; that is, under most bias conditions its transfer admittances are unequal. Within well-defined bias ranges its transfer admittances can be made unequal in magnitude though the same in sign, while in other well-defined ranges these admittances can be made to have opposite signs. It is in this last situation that the tetrode exhibits gyrator properties and is capable of inverting impedances. Most of the present discussion is directed toward that end.

Fig. 5 shows one of the simple cases in which the tetrode displays transfer admittances of opposite sign. Negative voltages are applied to terminals 1 and 3, but terminal 3 is made more negative to reverse bias the junction. Terminals 2 and 4 are both at ac and dc ground potential, while terminals 1 and 3 carry the signal voltages.

Several restrictions must be placed on signal and bias voltages. For quasi-linear operation, the magnitude of the signal voltage must be small compared to the dc voltage across the junction. This also automatically insures that the junction will never be forward biased. In addition, we will for present purposes rule out operation beyond pinch-off, because fundamental analysis of the device in that range has not yet been done.

Fig. 5 also gives an illustration of the fact that transfer admittances are opposite in sign for these bias conditions. When a positive increment ΔV_1 is placed on V_1, with V_3 held constant, reverse bias on the junction increases, the depletion layer expands, the resistance of channel 2 increases, and the current I_2 decreases—a change which can be represented by an *inward*-flowing incremental current ΔI_2. Applying a positive increment ΔV_2 to V_3, with V_1 held constant, causes the depletion layer to contract, and I_1 increases. This can be represented by an *outward*-flowing ΔI_1 on the left side.

If terminals 1 and 3 are both made positive, the currents and current increments change sign, but it is still true that a positive voltage increment leads to an inward current increment for one direction of transfer and to an outward current increment for the other direction.

However, by making terminal 1 positive and terminal 3 negative with respect to the common terminals, it can be seen by going through an argument similar to the one given above that the transfer admittances take on the same sign.

The dependence of the sign of the ratio of the transfer admittances, y_{12}/y_{21}, on bias is summarized graphically in Fig. 6. Here V_1 and V_3 are plotted against each other. The scales are normalized in terms of the pinch-off voltage W_P. Two lines are plotted, the lower corresponding to zero bias across the junction, $V_1 - V_3 = 0$, and the upper corresponding to the pinched-off condition, $V_1 - V_3 = W_p$. Hence, for a vanishingly small signal voltage, all bias combinations lying within the diagonal band are permissible. Limits at the ends of the region are fixed by dissipation considerations. The example given in Fig. 5 falls, of course, in the third quadrant.

For present purposes, discussion will be confined to the case of two independent dc biases and a common ground, as illustrated in Figs. 5 and 6; the principles are adequately demonstrated in this way, and all of the exploratory measurements to date have been made with this arrangement. Other possible biasing arrangements are taken up in Section V.

B. Admittance Analysis

As shown in Section II-A, (17) and (18), the current in each channel of a "symmetrical" tetrode can be expressed as a function of the dc voltages at the four terminals. These equations are based on a purely resistive model of the tetrode. The special case of Fig. 5 introduces the simplification that $V_2 = V_4 = 0$. Hence from these equations we can write,

$$I_1 = G_1 V_1 \left(1 - \frac{2}{3}\sqrt{\frac{V_1 - V_3}{W_P}}\right) \tag{38}$$

$$I_2 = G_2 V_3 \left(1 - \frac{2}{3}\sqrt{\frac{V_1 - V_3}{W_P}}\right). \tag{39}$$

From these equations the small-signal admittances, all real, can be calculated directly:

$$y_{11} = \frac{\partial I_1}{\partial V_1} = G_1\left[1 - \frac{3V_1 - 2V_3}{3\sqrt{W_P(V_1 - V_3)}}\right] \tag{40}$$

$$y_{22} = \frac{\partial I_2}{\partial V_2} = G_1 \frac{\mu_2}{\mu_1}\left[1 - \frac{2V_1 - 3V_3}{3\sqrt{W_P(V_1 - V_3)}}\right] \tag{41}$$

$$y_{12} = \frac{\partial I_1}{\partial V_3} = G_1 \frac{V_1}{3\sqrt{W_P(V_1 - V_3)}} \tag{42}$$

$$y_{21} = \frac{\partial I_2}{\partial V_1} = -G_1 \frac{\mu_2}{\mu_1} \frac{V_3}{3\sqrt{W_P(V_1 - V_3)}}. \tag{43}$$

It is of interest to compare the tetrode and an ideal gyrator in a straightforward way. An ideal gyrator is usually defined as a four-terminal element whose self-admittances, y_{11} and y_{22}, are zero and whose transfer admittances, y_{12} and y_{21}, are equal in magnitude and opposite in sign.[4] In the case where V_1 and V_3 are both negative, as shown in Fig. 5, it can be seen from (42) and (43) that the transfer admittances of the tetrode are indeed opposite in sign and will be equal in magnitude provided

$$\frac{\mu_2}{\mu_1} = \frac{V_1}{V_3}. \tag{44}$$

In Fig. 7 the dotted line in the first and third quadrants indicates this condition graphically for the case $\mu_2/\mu_1 = \frac{1}{3}$. Note that equal and opposite transfer admittances occur within the permissible bias range only in the third quadrant. They cannot be achieved by using positive biases on terminals 1 and 3.

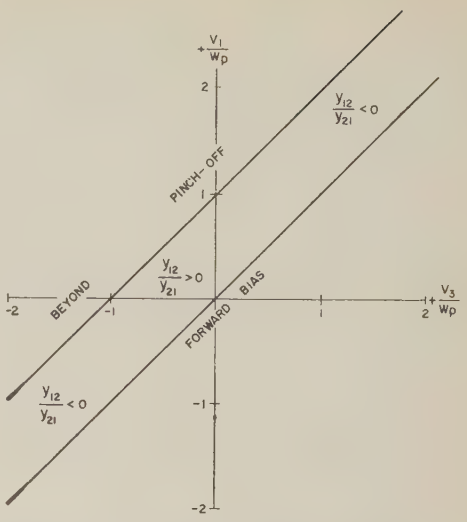


Fig. 6—Permissible range of bias voltages.

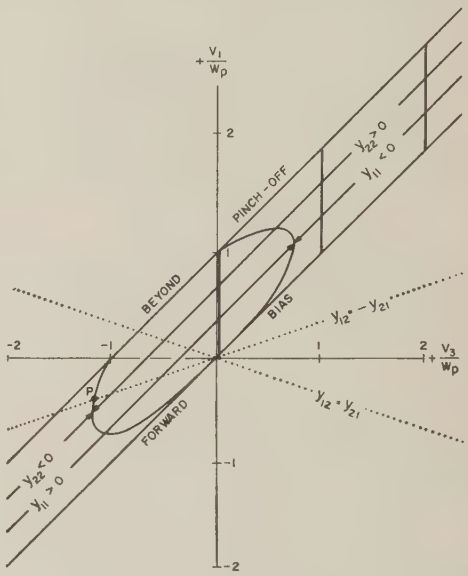


Fig. 7—Relationship between bias voltages and admittances.

Now consider the self-admittances: It is implicit in (40) that the minimum value of y_{11}, using negative biases, is obtained by letting $V_1 \to 0$ and $V_3 \to W_P$, which gives

$$y_{11} = \tfrac{1}{3}G_1. \tag{45}$$

Hence y_{11} remains positive and finite for permissible biases in the third quadrant. Additional insight can be gained here by means of a qualitative argument based on Fig. 5: a positive increment on V_1 decreases the end-to-end voltage on channel 1 and simultaneously increases its resistance; the reverse is true for a negative increment. Thus, the resistance and "driving voltage" changes are additive as far as channel current is concerned, so the self-admittance of channel 1 cannot vanish for these bias conditions.

[4] B. D. H. Tellegen, "The gyrator, a new electric network element," *Philips Res. Repts.*, vol. 3, pp. 80–101; April, 1948.

In channel 2, however, a positive increment on V_3 decreases the driving voltage but also decreases the channel resistance. It turns out that the two effects can be balanced to give zero change in I_2 and hence a zero value of y_{22}. Fig. 7 shows the locus of third-quadrant biases for which this is true.

Thus, by biasing at the point P in Fig. 7 ($V_1 = -18W_P/49$, $V_3 = -54W_P/49$), it is possible to have the transfer admittances equal and opposite, and to have one of the self-admittances, y_{22}, equal to zero. The other self-admittance has not vanished, however. Specifically, $y_{11} = (4/7)G_1$. This operating point has not proved to be the most advantageous one for practical impedance inversion, but it does illustrate the comparison of the field-effect tetrode with an ideal gyrator.

C. Inductor Analysis

A gyrator is capable of inverting an admittance. It can, for example, change the admittance of an ideal capacitor

$$y = j\omega C \tag{46}$$

into an ideal inductive admittance

$$y = \frac{y_t^2}{j\omega C}, \tag{47}$$

where y_t is the common magnitude of the ideal gyrator's transfer admittances. Hence for such an inductor,

$$L = \frac{C}{y_t^2}. \tag{48}$$

Because of the practical interest attaching to a miniature solid-state inductor, all experimental work to date on the gyrator aspect of the tetrode has been directed toward the inversion of capacitive admittances. We shall analyze this case and then give a specific numerical prediction based on this analysis for the behavior of the resulting inductor.

The input admittance at port 1 of a two-port network which is terminated on port 2 by an admittance y_{load} is

$$y_{in1} = y_{11} - \frac{y_{12}y_{21}}{y_{22} + y_{load}}. \tag{49}$$

For the situation where the load is at port 1, the input admittance similarly is

$$y_{in2} = y_{22} - \frac{y_{12}y_{21}}{y_{11} + y_{load}}. \tag{50}$$

Now let the two-port network be the field-effect tetrode, and let the load be a capacitor. The admittance of a capacitor having a leakage conductance G and a parasitic series resistance R_s can be written

$$y_c = \frac{G + G^2R_s + \omega^2C^2R_s + j\omega C}{1 + 2GR_s + G^2R_s^2 + \omega^2C^2R_s^2}. \tag{51}$$

This expression can be substituted into (49) and (50), and bulky expressions for effective Q and effective inductance can be obtained for each of the two configurations. These expressions are simplified, however, by considering the load to be a mica or other high-quality capacitor having a negligible series resistance.

For the leakage conductance of a mica capacitor in the range 10^2 to 10^7 cps we can write

$$G < \frac{\omega C}{10^3}. \tag{52}$$

This equation states that the Q of the capacitor is above 1000. The calculations are further simplified by assuming the Q to be equal to 1000 over the stated frequency range, for then

$$y_c = \omega C(10^{-3} + j). \tag{53}$$

To develop a specific example, let us select these first-quadrant biases:

$$V_1 = 0.75W_P$$
$$V_3 = 0.65W_P. \tag{54}$$

These values cause y_{11} in (49) to vanish. Making use of (53), it can be written

$$y_{in1} = -\frac{y_{12}y_{21}\left(y_{22} + \frac{\omega C}{10^3} - j\omega C\right)}{\left(y_{22} + \frac{\omega C}{10^3}\right)^2 + \omega^2C^2}. \tag{55}$$

Let us call this Case 1. For this case, the Q of the inductor is evidently

$$Q_1 = \frac{1}{10^{-3} + \frac{y_{22}}{\omega C}}, \tag{56}$$

and the inductance is

$$L_1 = -\frac{C}{y_{12}y_{21}}. \tag{57}$$

In a similar way we can write for Case 2, where the load admittance is on side 1,

$$y_{in2} = y_{22} - \frac{y_{12}y_{21}}{\omega C(10^{-3} + j)}. \tag{58}$$

Therefore,

$$Q_2 = \frac{1}{10^{-3} - \frac{\omega C y_{22}}{y_{12}y_{21}}}, \tag{59}$$

and

$$L_2 = -\frac{C}{y_{12}y_{21} - \frac{2y_{22}\omega C}{10^3} + \frac{y_{22}^2\omega^2C^2}{y_{12}y_{21}}}. \tag{60}$$

Eqs. (56), (57), (59), and (60) are plotted in Fig. 8. For purposes of this example, a value of 10^{-3} mho was chosen for G_1, the conductance of channel 1 with no voltage across the junction, and the value $\frac{1}{3}$ was taken for μ_2/μ_1. Thus it was possible to evaluate the admittances.

Fig. 8 shows Q and L vs frequency for three values of load capacitance. Multiple scales, labeled according to capacitance, are used for frequency and inductance. Evidently Case 1 is appropriate for high frequencies and Case 2 for low. It is implicit in (56) and (59) that the frequency for which the Q's are equal is given by

$$\omega = \frac{\sqrt{-y_{12}y_{21}}}{C}. \tag{61}$$

The value of Q at this frequency is given by

$$Q = \frac{\sqrt{-y_{12}y_{21}}}{y_{22}}, \tag{62}$$

and in this particular example its value is 0.86.

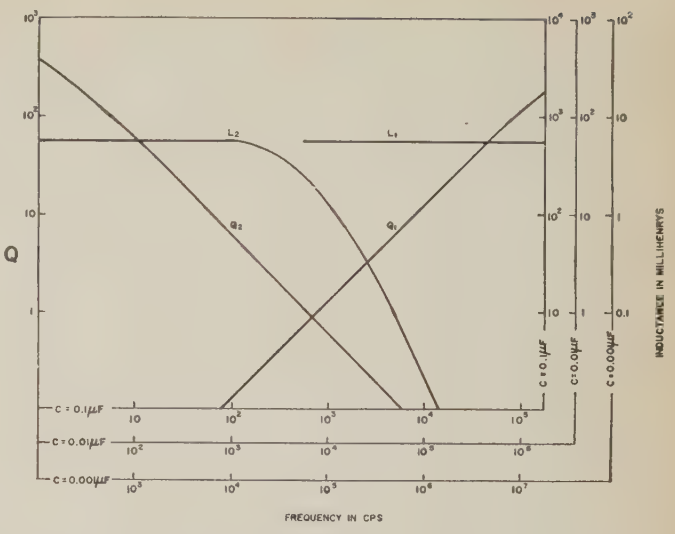


Fig. 8—Inductance and Q of field-effect gyrator with a capacitor load.

D. Experimental Results, Inductor

Because the self-admittance of a tetrode can be negative (Fig. 7), the bias arrangements must be made carefully to insure stable operation. This problem can be clarified by looking at tetrode input properties in terms of static current-voltage characteristics.

Let one of the independent biases be fixed, such as V_3 in Fig. 5, and then observe the dependence of I_1 on V_1. Let V_2 and V_4 be set equal to zero once more, but let V_1 and V_3 be made positive. Fig. 9 shows a family of I_1 vs V_1 characteristics, plotted from (38) for this case of first-quadrant bias. Note that voltage-controlled negative resistance (or "short-circuit-stable" negative resistance) is exhibited throughout the permissible bias range for all but one of the curves shown. The insert shows experimental confirmation of this behavior.[5]

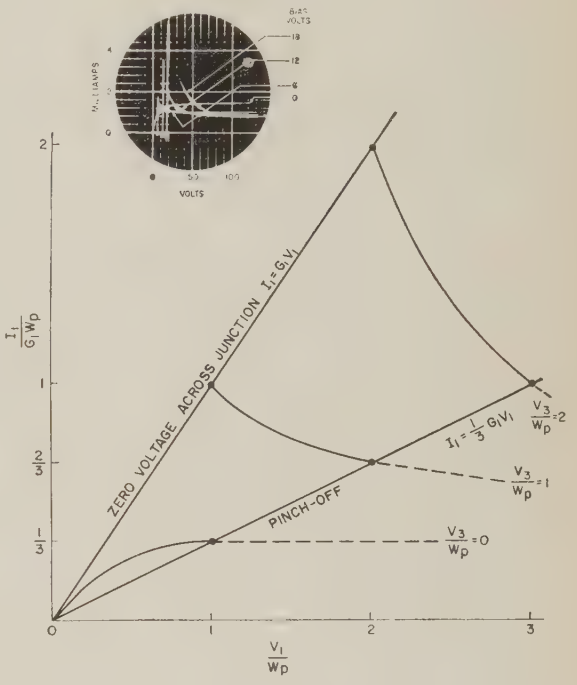


Fig. 9—Effect of biases on input characteristics.

The slope at any point of a curve in Fig. 9 is, of course, defined as y_{11} at that bias. The loci of bias points traversed in tracing out these curves are plotted as heavy lines in Fig. 7. Note that the lowest curve of Fig. 9, which shows positive slope, falls within the zone of Fig. 7 for which $y_{11}>0$, while the curves exhibiting negative slope fall outside it. The other self-admittance, y_{22}, is positive throughout the first quadrant.

A limited amount of experimental evidence indicates that negative input admittances will not occur at a given port if the channel on the opposite side is caused to pinch-off first by a thickness reduction through etching or some other means. For positive or first-quadrant biases where y_{11} is negative when W_{1P} is equal to or slightly less than W_{2P}, the experimental evidence suggests that y_{11} will be made positive by reducing W_{2P} to a value less than W_{1P}. A complementary statement applies to third-quadrant biases. Possibly this is related to the fact that the "current-limiter" characteristic of a given channel can be degraded by reducing the thickness of the opposite channel until it has a lower pinch-off voltage, because the pattern of available charges in the "gate" is altered by such a change in the thickness of the gate region.

[5] The nearly vertical regions in the trace are not significant, since here the junction is forward biased and as a result the current in channel 1 (I_1) and the current *to* terminal 1 are no longer the same. It is the latter current which is being recorded. It changes very rapidly with V_1 and can even be negative for small V_1 because V_3 then drives current backward through the V_1 supply.

Experimental results indicate an advantage insofar as Q is concerned in biasing to obtain negative self-admittance. The tetrode for which the following data are reported exhibited this property in the first quadrant, and our measurements are restricted to this condition. Furthermore, frequency limitations in our bridge and exploratory circuit confined us to Case 2, or low-frequency measurements. In this configuration, the port of negative or potentially negative self-admittance faces the capacitor. Hence, the bias supply on the side of the capacitative load is most critical from the point of view of stable operation. As is well known, stable operation in a voltage-controlled negative-resistance region requires a source resistance (or load resistance) R less than the magnitude of the negative resistance at the point in question. Fig. 10 shows that such a value of R is necessary to achieve a single intersection of the I-V characteristic by the load line. In the Case 2 configuration, R is in shunt with the capacitor, lowering the Q of the reactance which the tetrode is to invert.

In the experimental reconciliation of these conflicting requirements, large R for efficiency and small R for stability, low Q inductances were the result. The Q values were at most of the order of unity.

Study of Fig. 10 suggests that one could move the operating point to the right, thus avoiding the most steeply descending portion of the I_1V_1 characteristic and permitting a larger R. This amounts to increasing $V_1 - V_3$. But another consideration imposes limitations here: Eq. (59) shows that Q_2 is favored by a large value of $y_{12}y_{21}/y_{22}$. From (41), (42) and (43),

$$\frac{y_{12}y_{21}}{y_{22}} = -\frac{G_1V_1V_3}{3\sqrt{W_P(V_1-V_3)}\left[3\sqrt{W_P(V_1-V_3)}-(2V_1-3V_3)\right]}. \tag{63}$$

Thus Q_2 is enhanced by small $V_1 - V_3$. The transfer admittances (or transconductances) y_{12} and y_{21} are a maximum for zero voltage across the junction for the same reason that transconductance in a field-effect transistor is a maximum for zero gate bias. The rate of change of depletion-layer thickness with respect to voltage is greatest near zero voltage. Experimentally we were limited to values of $V_1 - V_3$ less than 4 volts to have usably high transconductances.

Eq. (63) shows that G_1 should be increased to enhance $y_{12}y_{21}/y_{22}$ and, therefore, Q_2 for a given W_P and a given set of biases. This can be accomplished by increasing Z/L, which increases G_1 without affecting W_P. Therefore, the ideal tetrode for low frequency or Case 2 operation should be a "high-Z/L" device. Note in (56), however, that the high-frequency quality factor Q is favored by small y_{22}, and hence small G_1. Thus, our relatively low-conductance devices ($G_1 = 100$–500 μmho) might have performed better in Case 1 operation.

Four tetrodes were used in these experiments but only two gave measurable inductance. One did so with first-quadrant biasing and the other with third-quadrant biasing. The former gave the best results and some of these only are reported. It is unfortunate that the most symmetrical tetrodes were damaged in handling before this phase of the work.

All of the exploratory inductance measurements reported here were made with a Maxwell bridge having a superimposed dc feature which supplied one of the two tetrode biases. Results were obtained in terms of equivalent series inductance and resistance. The bridge, a rather elaborate one, exhibited good sensitivity down to Q values as low as 0.1.

Fig. 11 shows the circuit which, except for minor variations, was used for all of the following measurements. The transistor was used as a very high impedance or constant current source. It was shunted by a variable resistor in order to adjust to varying amounts of negative resistance in the I_1-V_1 characteristic and also to observe the effect on the inductor of changing capacitor Q.

Fig. 12(a) shows measured L_2 and Q_2 vs frequency for $C_L = 1000$ $\mu\mu$f and $R = 10^6$ ohms. For comparison, the Q of the capacitor combined with the shunting resistor is

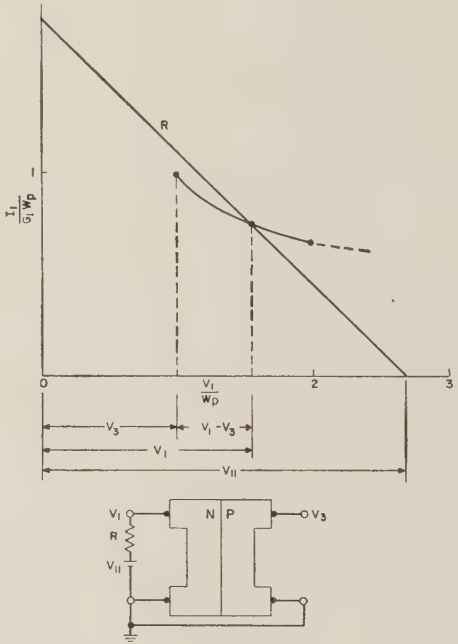


Fig. 10—Load line condition for field-effect tetrode terminated in resistance.

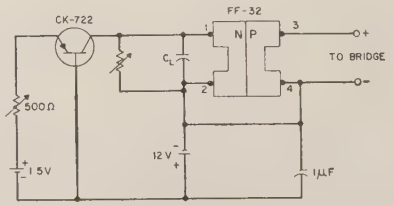


Fig. 11—Circuit used for impedance inversion with field-effect tetrodes.

also plotted. Evidently, this cuts down the Q of the inductor on the low-frequency side. Thus Q_2 peaks at about 12 kc. V_{ac} is the magnitude of the signal voltage applied to the bridge.

Similar data are plotted in Fig. 12(b) and 12(c) for $C_L = 3800$ $\mu\mu$f and for two values of R. Here Q_2 rises above unity but both peaks occur at lower frequencies.

Direct comparison with the simple theory is not possible because the two channels in this particular tetrode did not pinch-off simultaneously. But there is evident qualitative agreement between Figs. 8 and 12 with respect to the constant L_2 in the neighborhood of the Q_2 maximum, and the falling L_2 at higher frequencies.

The magnitude of inductor Q which has so far been obtained is much too low for practical application. However, the measurements have confirmed the expected nonreciprocity, and the analysis indicates that, with units having higher Z/L, improvements in Q may be expected.

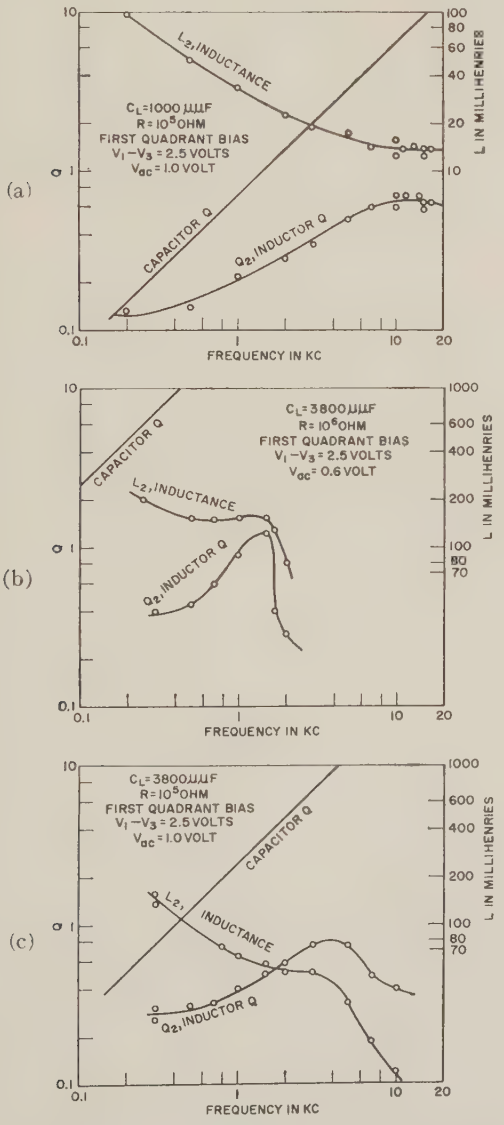


Fig. 12—Measured inductance and Q of field-effect tetrode terminated by (a) 1000 $\mu\mu$f, 10^5 ohms, (b) 3800 $\mu\mu$f, 10^6 ohms and (c) 3800 $\mu\mu$f, 10^5 ohms.

V. Isolator and Negative Impedance Inverter

When the field-effect tetrode is biased at a point on one of the axes in Fig. 7, and again assuming $V_2 = V_4 = 0$, one of the channels carries no current and hence there can be no output to a load on that side. Under such conditions the device is an "isolator," for it transmits signals in one direction but blocks signals in the other. Because the isolation so achieved can be made to face in either direction simply by choice of bias, the tetrode can be regarded as an isolation "switch." The field-effect transistor is, by comparison, a unidirectional isolator.

When biased at a point on the dotted line in the second quadrant of Fig. 7, a simultaneous pinch-off tetrode exhibits transfer admittances which have the same sign and are equal in magnitude. Thus it becomes a negative impedance inverter, and would, for example, convert a capacitative load into a negative inductance.

The situation depicted in Figs. 5 and 6 can be generalized by giving one of the common terminals a variable dc bias while holding it at ground with respect to ac. When a third dimension V_4/W_P is added to Fig. 6, the region of permissible bias expands into a rectangular prism and the condition $y_{12}/y_{21} > 0$ obtains within an inscribed tetrahedral volume of which the triangle in Fig. 6 is one face.

A common ac ground of diagonally opposite terminals yields a complementary situation. If terminals 2 and 3 are so connected, for example, the condition $y_{12}/y_{21} > 0$ holds in those regions of the prism of permissible biases lying outside the tetrahedron mentioned above. With this arrangement, the depletion layer is free to fluctuate at both ends, while in the situation shown in Fig. 5 it can vary only at one end. To this degree, at least, the two situations are not strictly complementary. The case of depletion-layer variations at both ends has not been treated exhaustively, but it may hold some interest because of its greater flexibility.

VI. Electronically Variable Resistor

The unique qualities of the field-effect tetrode in this application can be appreciated by first considering a field-effect triode[2] in the same application. If the triode is connected as shown in Fig. 13(a), it can indeed be used as an electronically variable resistor. Control voltage V_g alters the resistance of the channel. However, signal voltage applied to this resistor also modulates the depletion layer and hence the resistance of the channel. For quasi-linear operation, therefore, the signal voltage must be kept small compared to the pinch-off voltage of the device. Further, a frequency limitation exists because the junction capacitance shunts the signal to ground.

Fig. 13(b) illustrates the principle involved in using a field-effect tetrode as an electronically variable resistor. The bias voltage V_b establishes a uniform deple-

tion layer through the junction region. A capacitor C, whose reactance is small compared to channel resistance at the frequency of the signal voltage V_s, insures that the signal voltage will not appear to any significant degree across the junction. Therefore, signal voltage can exceed bias voltage, pinch-off voltage, and even junction breakdown voltage. Limits on signal are set by dissipation considerations. To an excellent approximation the full signal voltage is applied from end-to-end on the two channels in parallel, and signal currents flow in inverse ratio to the channel resistances.

Because signal modulation of the depletion layer is thus eliminated, the tetrode can be used as a variable resistor for very high-frequency signals.

Fig. 14 shows a practical circuit which includes a load resistance R_L. The resistor R_s has a value, small compared with the resistance of the junction, with which it is in series, but large enough for isolation purposes. In this circuit, V_b can be a dc bias, as before, or it can be a low-frequency ac voltage which modulates the signal from V_s. Thus the tetrode can function as a nondistorting modulator. In this case, the capacitors C must be chosen for small reactance at the frequency of V_s and large reactance at the frequency of V_b. They and the junction capacitance limit the bias frequency.

From such a modulator it is a short step to an amplifier wherein V_s is a "pump" source driving large amounts of power into R_L in the form of a signal which is modulated by the low power signal V_b.

For analysis of the configuration shown in Fig. 14, we observe the following voltages at the terminals of the device:

$$V_1 = V_b + V_s$$
$$V_2 = V_b + V_0$$
$$V_3 = V_s$$
$$V_4 = V_0.$$

Putting these values in (17) and (18), the total current is

$$I = I_1 + I_2 = (G_1 + G_2)(V_s - V_0)\left(1 - \sqrt{\frac{V_b}{W_P}}\right). \quad (64)$$

The effective resistance of the tetrode to the signal voltage is

$$R = \frac{V_s - V_0}{I} = \frac{1}{(G_1 + G_2)\left(1 - \sqrt{\frac{V_b}{W_P}}\right)}. \quad (65)$$

Normalized in terms of the resistance for zero bias, this becomes

$$\frac{R}{R_0} = \frac{1}{1 - \sqrt{\frac{V_b}{W_P}}}. \quad (66)$$

This characteristic is plotted in Fig. 15.

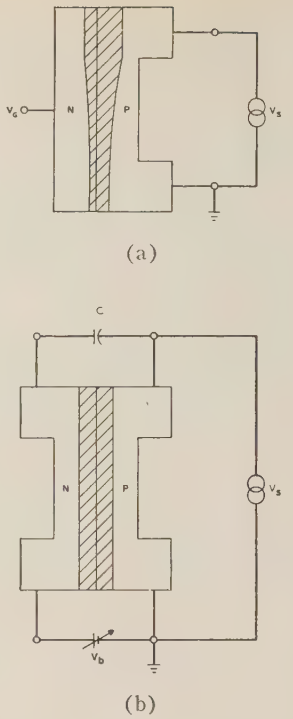


Fig. 13—Principle of (a) field-effect transistor and (b) field-effect tetrode as electronically variable resistor.

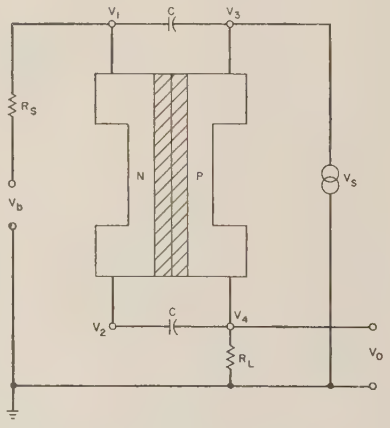


Fig. 14—Laboratory circuit for using field-effect tetrode as electronically variable resistor.

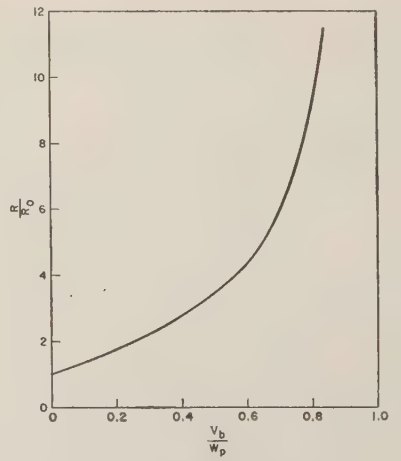


Fig. 15—Resistance vs bias for field-effect tetrode as electronically variable resistor.

Unsymmetrical tetrodes can also be used as electronically variable resistors. But if one of the channels has appreciable conductance when the other is pinched off, then the "tuning range" or maximum R/R_0 is limited. The models available when experiments were done on this mode of operation were quite unsymmetrical, and the range of controlled resistance variation was about 2.5 to 1.

VII. Structure and Fabrication

Fig. 16 shows the structure of the exploratory field-effect tetrode. A sectioned view is presented to show more clearly the relationship between the schematic structure considered above and the geometry of an actual device. A circular shape was chosen to achieve reasonable mechanical strength in spite of the thin web which constitutes the channel region. To make this web as thick as possible, high resistivity-starting material and a deep low-gradient junction were employed.

Steps in fabricating such a field-effect tetrode can be outlined as follows: Starting with a 0.020-inch slice of 100-ohm-cm P-type silicon, phosphorus is diffused into the surface to produce an N layer 0.004 inch thick. One side of the slice is lapped reducing the slice thickness to 0.008-inch, thus producing a slice with a junction at its median plane. A light boron diffusion is performed on the P side to cut down contact and spreading resistance in the final device. The slice is gold plated heavily on both sides, and disks 0.100 inch in diameter are cut out using an ultrasonic tool. Opposed circular trenches are then cut on the two sides of the disk using either another ultrasonic tool or a rotating tube (*i.e.*, by trepanning). An abrasive must be used in either case. The mean diameter of a trench is typically 0.060 inch and its L dimension (outside-minus-inside radius) is about 0.005 inch.

If sufficiently fine abrasives are used, it is possible to finish the surface of the trench without etching. Otherwise, light etching is necessary to remove damaged material. Etching can also be used, of course, to make fine reductions in channel thickness in order to adjust channel resistance. In practice, it has always been necessary thus far to make final adjustments in channel thickness on a cut-and-try basis, using electrical characteristics of the device as criteria. These final adjustments in channel thickness have been made successfully both by etching and by polishing alone, using the trepanning method. Final channel thicknesses are typically 0.0007 inch for the P side and 0.0003 inch for the N side.

In fabricating field-effect tetrodes it is often helpful to compare the channels by testing each one in turn as a current-limiter channel.[6] From (17) and (18) it can be shown that when simultaneous pinch-off has been achieved, the "pinch-off currents" of the two channels will stand in the ratio of the mobilities. This has been confirmed experimentally. However, a rather high degree of precision in channel shaping and placement is necessary to demonstrate this behavior. If a good current-limiter characteristic is achieved on side 1, and side 2 is subsequently cut a little too deeply, the characteristic of side 1 will be degraded, as mentioned in Section IV-D. Fortunately, unsymmetrical as well as symmetrical devices exhibit the unique tetrode properties, though in lesser degree.

Finally, leads are attached to the four isolated gold-plated regions of the disk and are welded to the header leads. Fig. 17 shows a completed tetrode. The leads in this case are 0.003-inch gold on the outer rim and 0.015-inch gold at the center, all attached by thermocompression bonding.

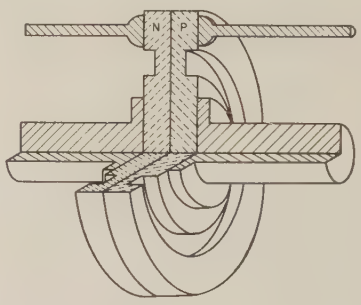


Fig. 16—Circular geometry of the field-effect tetrode.



Fig. 17—Field-effect tetrode mounted on header.

Appendix I

The Space-Charge Depth on Either Side of Junction Formed by Uniformly but Unequally Doped Regions

Fig. 18 shows schematically a junction between an N region with uniform donor density N and a P region with uniform acceptor density P. A voltage V is applied across the junction and this gives rise to a space-charge layer of thickness t_1 in the N region and t_2 in the P region. We wish to find t_1 as a function of the impurity densities and the applied voltage.

In the N region, Poisson's equation is

$$\frac{d^2\Psi}{dx^2} = -\frac{qN}{\kappa\epsilon_0}. \tag{67}$$

[6] R. M. Warner, Jr., W. H. Jackson, E. I. Doucette, and H. A. Stone, Jr., "A semiconductor current limiter," Proc. IRE, vol. 47, pp. 44–56; January, 1959.

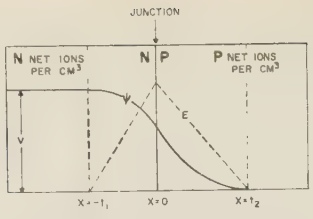


Fig. 18—Potential and field within uniformly but unequally doped regions in a semiconductor.

For the P side, it is

$$\frac{d^2\Psi}{dx^2} = -\frac{(-q)P}{\kappa\epsilon_0}. \tag{68}$$

Integrating:

$$\frac{d\Psi}{dx} = -\frac{qN}{\kappa\epsilon_0}(x + C_1) \tag{69}$$

$$\frac{d\Psi}{dx} = \frac{qP}{\kappa\epsilon_0}(x + C_2). \tag{70}$$

When $x = -t_1$, that is, at the depletion-layer boundary in the N region, $d\Psi/dx = 0$. Therefore $C_1 = t_1$. Also, when $x = t_2$, $d\Psi/dx = 0$, so $C_2 = -t_2$.

Therefore,

$$\frac{d\Psi}{dx} = -\frac{qN}{\kappa\epsilon_0}(x + t_1) \tag{71}$$

$$\frac{d\Psi}{dx} = \frac{qP}{\kappa\epsilon_0}(x - t_2). \tag{72}$$

Both equations are valid when $x = 0$. Thus we can derive

$$\frac{t_1}{t_2} = \frac{P}{N}. \tag{73}$$

Integrating again:

$$\Psi = -\frac{qN}{\kappa\epsilon_0}\left(\frac{x^2}{2} + t_1 x + C_{11}\right) \tag{74}$$

$$\Psi = \frac{qP}{\kappa\epsilon_0}\left(\frac{x^2}{2} - t_2 x + C_{22}\right). \tag{75}$$

On the N side where $x = -t_1$, $\Psi = V$. Therefore,

$$C_{11} = \frac{\kappa\epsilon_0 V}{qN} + \frac{t_1^2}{2}.$$

On the P side where $x = t_2$, $\Psi = 0$. Therefore,

$$C_{22} = \frac{t_2^2}{2}.$$

So (74) and (75) become

$$\Psi = V - \frac{qN}{\kappa\epsilon_0}\left(\frac{x^2}{2} + t_1 x + \frac{t_1^2}{2}\right) \tag{76}$$

$$\Psi = \frac{qP}{\kappa\epsilon_0}\left(\frac{x^2}{2} - t_2 x + \frac{t_2^2}{2}\right). \tag{77}$$

When $x = 0$, both equations are valid and

$$\Psi_0 = V - \frac{qNt_1^2}{2\kappa\epsilon_0} = \frac{qPt_2^2}{2\kappa\epsilon_0}. \tag{78}$$

But, from (71)

$$t_2 = \frac{N}{P} t_1.$$

So

$$t_1^2 = \frac{2\kappa\epsilon_0}{q}\,\frac{N}{P}\,\frac{V}{N+P} \tag{79}$$

and

$$t_2^2 = \frac{2\kappa\epsilon_0}{q}\,\frac{N}{P}\,\frac{V}{N+P}. \tag{80}$$

Substituting (79) in (78), the potential at the junction is seen to be

$$\Psi_0 = \frac{N}{N+P} V. \tag{81}$$

Appendix II

Unrestricted Current-Voltage Equations

Eqs. (17) and (18) are valid only if the pinch-off voltages in the two channels are exactly equal. In this appendix, current-voltage equations are derived without any restrictions on the relative magnitudes of the pinch-off voltages. Approximate solutions are then derived for the case where the pinch-off voltages are nearly equal. The simplifying assumptions outlined in Section II apply here also.

In view of (1)–(4), the differential equations (11) and (12) may be written

$$I_1 = -G_1 L\left(1 - \sqrt{\frac{v_1 - v_2}{W_{1P}}}\right)\frac{dv_1}{dx} \tag{82}$$

$$I_2 = -G_2 L\left(1 - \sqrt{\frac{v_1 - v_2}{W_{2P}}}\right)\frac{dv_2}{dx}, \tag{83}$$

or

$$\alpha_1 = (\mu - \beta_1)\frac{dv_1}{dx} \tag{84}$$

$$\alpha_2 = (\mu - \beta_2)\frac{dv_2}{dx}, \tag{85}$$

where

$$\alpha_i = \frac{I_i \beta_i}{G_i L} \tag{86}$$

$$\beta_i = \sqrt{W_{iP}} \tag{87}$$

$$\mu = \sqrt{v_1 - v_2}. \tag{88}$$

For the first solution,

$$(\alpha_1 - \alpha_2)\int_0^L dx = 2\int_{\sqrt{V_1 - V_3}}^{\sqrt{V_2 - V_4}} u^2 d\mu - \beta_1 \int_{V_1}^{V_2} dv_1 + \beta_2 \int_{V_3}^{V_4} dv_2 \tag{89}$$

$$(\alpha_1 - \alpha_2)L = \beta_1(V_1 - V_2) - \beta_2(V_3 - V_4) - \frac{2}{3}\left[(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}\right]. \tag{90}$$

The second solution is obtained from (84) and (85) as follows:

$$\frac{dv_1}{dx} - \frac{dv_2}{dx} = 2\mu\frac{d\mu}{dx} = \frac{\alpha_1}{\mu - \beta_1} - \frac{\alpha_2}{\mu - \beta_2} \tag{91}$$

$$(\alpha_1 - \alpha_2)dx = 2\frac{\mu^3 - (\beta_1 + \beta_2)\mu^2 + \beta_1\beta_2\mu}{\mu - \gamma}\, d\mu, \tag{92}$$

where

$$\gamma \equiv \frac{\alpha_1\beta_2 - \alpha_2\beta_1}{\alpha_1 - \alpha_2}. \tag{93}$$

Eq. (92) reduces to

$$(\alpha_1 - \alpha_2)dx = 2\left\{\mu^2 + [\gamma - (\beta_1 + \beta_2)]\mu + [(\gamma - \beta_1)(\gamma - \beta_2)] + \frac{\gamma(\gamma - \beta_1)(\gamma - \beta_2)}{\mu - \gamma}\right\} d\mu. \tag{94}$$

Integrating along the length of the channel

$$(\alpha_1 - \alpha_2)L = -\frac{2}{3}\left[(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}\right] - [\gamma - (\beta_1 + \beta_2)][(V_1 - V_3) - (V_2 - V_4)] - 2[(\gamma - \beta_1)(\gamma - \beta_2)][\sqrt{V_1 - V_2} - \sqrt{V_2 - V_4}] - 2\gamma[(\gamma - \beta_1)(\gamma - \beta_2)]\ln\frac{\sqrt{V_1 - V_3} - \gamma}{\sqrt{V_2 - V_4} - \gamma}. \tag{95}$$

The appearance of (95) can be improved by subtracting it from (90) and putting in the value for γ. It becomes

$$\frac{(\alpha_1 - \alpha_2)^2}{\beta_1 - \beta_2}\left[\frac{V_1 - V_2}{\alpha_1} - \frac{V_3 - V_4}{\alpha_2}\right] - 2(\alpha_1 - \alpha_2)\left[\sqrt{V_1 - V_3} - \sqrt{V_2 - V_4}\right] - 2(\alpha_1\beta_2 - \alpha_2\beta_1)\ln\frac{(\alpha_1 - \alpha_2)\sqrt{V_1 - V_3} - (\alpha_1\beta_2 - \alpha_2\beta_1)}{(\alpha_1 - \alpha_2)\sqrt{V_2 - V_4} - (\alpha_1\beta_2 - \alpha_2\beta_1)} = 0. \tag{96}$$

Eqs. (90) and (96) contain implicitly the solutions for α_1 and α_2 and thus for I_1 and I_2, in terms of the applied voltages. Because of the log term in (96), they are intractable except when restrictions are put on the pinch-off voltages.

If β_1 is nearly equal to β_2 (and if $\alpha_1 \neq \alpha_2$), the first term in (96) predominates and it becomes approximately

$$\frac{(\alpha_1 - \alpha_2)^2}{\beta_1 - \beta_2}\left[\frac{V_1 - V_2}{\alpha_1} - \frac{V_3 - V_4}{\alpha_2}\right] = 0 \tag{97}$$

$$\frac{V_1 - V_2}{\alpha_1} = \frac{V_3 - V_4}{\alpha_2}. \tag{98}$$

Solving (94) and (102) simultaneously

$$\alpha_1 = \frac{V_1 - V_2}{L}\left\{\frac{\beta_1(V_1 - V_2) - \beta_2(V_3 - V_4)}{(V_1 - V_2) - (V_3 - V_4)} - \frac{2}{3}\frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right\}. \tag{99}$$

$$\alpha_2 = \frac{V_3 - V_4}{L}\left\{\frac{\beta_1(V_1 - V_2) - \beta_2(V_3 - V_4)}{(V_1 - V_2) - (V_3 - V_4)} - \frac{2}{3}\frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right\} \tag{100}$$

or, from (86) and (87)

$$I_1 = G_1(V_1 - V_2)\left\{\frac{(V_1 - V_2) - \sqrt{\frac{W_{2P}}{W_{1P}}}(V_3 - V_4)}{(V_1 - V_2) - (V_3 - V_4)} - \frac{2}{3\sqrt{W_{1P}}}\frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right\}. \tag{101}$$

$$I_2 = G_2(V_3 - V_4)\left\{\frac{\sqrt{\frac{W_{1P}}{W_{2P}}}(V_1 - V_2) - (V_3 - V_4)}{(V_1 - V_2) - (V_3 - V_4)} - \frac{2}{3\sqrt{W_{2P}}}\frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right\}. \tag{102}$$

Since $W_{1P} \approx W_{2P}$, a further approximation can be made

$$I_1 = G_1(V_1 - V_2)\cdot\left\{1 - \frac{2}{3\sqrt{W_{1P}}}\frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right\}. \tag{103}$$

$$I_2 = G_2(V_3 - V_4)\cdot\left\{1 - \frac{2}{3\sqrt{W_{2P}}}\frac{(V_1 - V_3)^{3/2} - (V_2 - V_4)^{3/2}}{(V_1 - V_3) - (V_2 - V_4)}\right\}. \tag{104}$$

Acknowledgment

The authors are indebted to E. F. O'Connell, Jr. for exploratory device fabrication, and to W. H. Jackson, J. M. Sipress, and W. J. Grubbs for assistance in the analysis.

An Experimental Study of Bistatic Scattering from Some Small, Absorber-Coated, Metal Shapes*

R. J. GARBACZ†, MEMBER, IRE, AND D. L. MOFFATT†, MEMBER, IRE

Summary—Experimental data are presented on the bistatic scattering cross sections of some small metal bodies, uncoated and coated with a resonant, lossy layer. All of the targets—spheres, cylinders, and cones—are of a size to be in the resonant region at wavelengths of approximately 3 cm. All of the bodies indicate a similar trend—the coated bodies are effectively camouflaged in the back hemisphere, but not in the forward hemisphere. In the forward direction, the scattering cross sections of the coated bodies are at least as large as, or larger than, those of the uncoated bodies. The bistatic angles beyond which this enhancement is effective become smaller as the electrical size of the body decreases, *i.e.*, as frequency decreases.

Introduction

THE purpose of this experimental study is to investigate the scattering characteristics of some simple shapes coated with a lossy, resonant material. Data are presented on the bistatic scattering cross sections of spheres, cylinders, and cones of the order of one to three wavelengths in circumference at X-band frequencies. In each case, scattering from the uncoated body and that from its coated counterpart are compared for both vertical and horizontal polarizations of the incident E field and scattered E field. (The term, "coated counterpart," will always mean the uncoated body simply coated by the constant thickness absorbing material.) The absorber used on all the bodies is a lossy, resonant type developed at the Naval Research Laboratory.[1] Fabrication techniques are given.[2] The permeability of this absorber is frequency-sensitive and so necessitates a change in composition with change in desired resonant (optimum absorption) frequency. For any given composition there is a critical layer thickness for resonance. Also, a given material which is resonant when coating a flat surface is generally not resonant at the same frequency when coating curved surfaces, which necessitates "custom fitting" the absorber to such curved surfaces if optimum performance is to be realized. The targets used for this report were borrowed from the Naval Research Laboratory and are the same ones discussed by Wright, *et al.*[1] They are coated with an absorber whose thickness and composition were determined by the Naval Research Laboratory for flat plate resonance at about $\lambda = 3.2$ cm, and whose relative constitutive constants are $\mu_2 \cong 1.5 + j1.5$ and $\epsilon_2 \cong 8 + j0.5$. The thickness of the coating is 0.077 inch. It should be evident from the above that the data presented here do not necessarily represent optimum performance of the absorber.

Results of the following tests will be found in this paper:

1) Scattering cross sections, for bistatic angles of 0° to 160°, of uncoated metal spheres 0.50 inch, 1.00 inch, and 1.587 inches in diameter, and their coated counterparts, were recorded at frequencies of 8.65 kMc, 9.375 kMc, and 10.00 kMc. In addition, uncoated metal spheres 0.25 inch, 0.40 inch, and 1.312 inches in diameter and their coated counterparts were recorded at 10.00 kMc. For each of these tests, vertical polarization of the E field was first transmitted and received, then horizontal polarization of the E field was transmitted and received. The receiver was separated from the transmitter by the bistatic angle β, measured in the horizontal plane.

2) Scattering cross sections, for bistatic angles of 0° to 160°, of uncoated metal rods 5 inches long and 0.155 inch, 0.200 inch, 0.310 inch, 0.400 inch, 0.470 inch, 0.620 inch, and 0.780 inch in diameter, and their coated counterparts (except that the ends were left uncoated), were recorded at 10.00 kMc. 180° azimuth patterns were taken at each bistatic angle by rotating the rods about a vertical axis normal to the longitudinal axes of the rods. Vertical polarization of the E field was first transmitted and received, then horizontal polarization of the E field was transmitted and received.

3) Scattering cross sections, for bistatic angles of 0° to 160°, of an uncoated metal right circular cone with a slant height of 2.86 inches and an apex angle of 38.5°[3] and its coated counterpart, were recorded at 9.375 kMc. Two sets of 180° azimuth patterns were taken, by rotating the cones about a vertical axis normal to and at 45° to the axis of symmetry of the cones. For each of these orientations, vertical polarization of the E field was first transmitted and received, then horizontal polarization of the E field was transmitted and received.

A brief description of the test equipment is included in the Appendix.

* Received by the IRE, November 7, 1960; revised manuscript received, April 3, 1961. This work was supported by Rome Air Dev. Ctr., Griffiss AFB, Rome, N. Y., under contract AF 30(602)-2042.

† Antenna Lab., Dept. of Elec. Engrg., The Ohio State University, Columbus, Ohio.

[1] R. W. Wright, W. H. Emerson, and D. H. Phillips, "Reflectivity of camouflaged small simple objects," *Proc. Second Annual RADC Internatl. RAM Symp.*, Rome Air Dev. Ctr., Griffiss AFB, Rome, N. Y., Secret, vol. 2, pp. 80–84, spheres; pp. 75–77, cylinders; pp. 78–80, cones; June, 1959.

[2] W. H. Emerson and M. V. McDowell, "Radar camouflage of warhead models," *Proc. Second Annual RADC Internatl. RAM Symp*, Rome Air Dev. Ctr., Griffiss AFB, Rome, N. Y., Secret, vol. 2, pp. 89–90; June, 1959.

[3] Wright, *et al.*, *op. cit.*, this is the cone designated "B," p. 78.

Experimental Results

A. Spheres

In order that there be no confusion about what data were taken, Fig. 1 sketches the geometry of the scattering patterns. The coordinate system used is the standard spherical one, with the E field of the incident wave directed in the x direction and propagating in the positive z direction. The H plane scattering patterns are those in which the scattered E field, which is polarized in the x direction, is detected by a receiver that moves in the y-z plane and is separated from the transmitter by a bistatic angle β. The E plane scattering patterns are those in which the scattered E field, which is polarized in the θ direction (θ is measured from the $+z$ axis as usual), is detected by a receiver that moves in the x-z plane and is separated from the transmitter by a bistatic angle β. In actual darkroom practice, the H plane patterns were taken with the transmitter and receiver polarizations, shown in Fig. 1, by moving the receiver in a horizontal (y-z) plane along a semicircular track built into the floor. Then, in order to record the E plane patterns and retain use of the track, the polarization of the incident E field was rotated 90° and the receiver antenna was rotated 90°. The targets were rotated by means of strings about a vertical axis, the azimuth or rotation angle being θ, and $\theta=0$ when the projection of the symmetry axis of the body onto a horizontal plane corresponded to the transmitter direction. The bistatic scattering cross sections of several sphere sizes at three frequencies are given in Figs. 2–4 (pp. 1186–1187). The broken lines represent the uncoated spheres, and the solid lines represent the coated spheres. On each polar plot, the left side gives data for vertical polarization of the transmitted and received E fields (called H-plane patterns), and the right side gives data for horizontal polarization of the transmitted and received E fields (called E-plane patterns). The radial coordinate represents the bistatic scattering cross section, σ, in db above or below one square wavelength and the angular coordinate represents the bistatic angle β.

Figs. 5–7 (p. 1188) are plots of the reduction or enhancement of the bistatic scattering cross sections due to the absorber coating.

Some remarks concerning the validity of the data should be made here. The scatter-measuring range used in these experiments was capable of "seeing" targets which were 26 db below a square wavelength within ± 2 db. Returns below this level are correspondingly less accurate, and when they appear on the data they should be taken only as approximations. Thus, in some cases the backscatter ($\beta=0°$), which should be independent of incident polarization for spheres and which presents the lowest return levels to the measuring system, differs slightly for the two polarizations. This is a measure of the experimental accuracy at these levels. On the other hand, when the scattering cross sections are greater than 15 db below a square wavelength, the data are accurate within ± 0.5 db. These limitations should be considered when looking at the echo enhancement and reduction curves. Fig. 8 is an example of the actual recorded data for a one-inch diameter sphere, uncoated and coated, at $f=8.65$ kMc, $\beta=40°$ and horizontal polarization. A record of the nulled background signal with no scatterer present is also given. The levels of the uncoated spheres were rarely in question, but those of the coated spheres were obtained by a visual averaging of the variations.

B. Cylinders

The bistatic scattering cross sections of seven 5-inch rods with uncoated diameters of 0.155 inch to 0.780 inch were measured at 10 kMc, coated and uncoated, for both polarizations. Fig. 9 shows typical azimuth patterns for the uncoated and coated bodies. Fig. 10 (p. 1189) is a plot of the scattering cross-section reduction or enhancement due to absorber coating for the broadside specular reflection; Fig. 11 gives the same information in a different manner. Note in these last figures that λ is a constant in the abscissa variable d/λ.

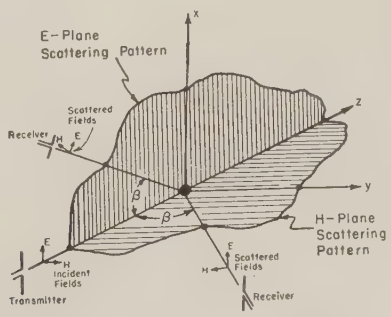


Fig. 1—The E-plane and H-plane scattering patterns, which lie, respectively, in the planes of the incident E vector and H vector. For convenience in the darkroom, instead of measuring the E-plane pattern in a plane normal to the floor as indicated in this diagram, the polarizations of the transmitter and receiver were rotated 90° and the E-plane pattern was measured in a plane parallel to the floor.

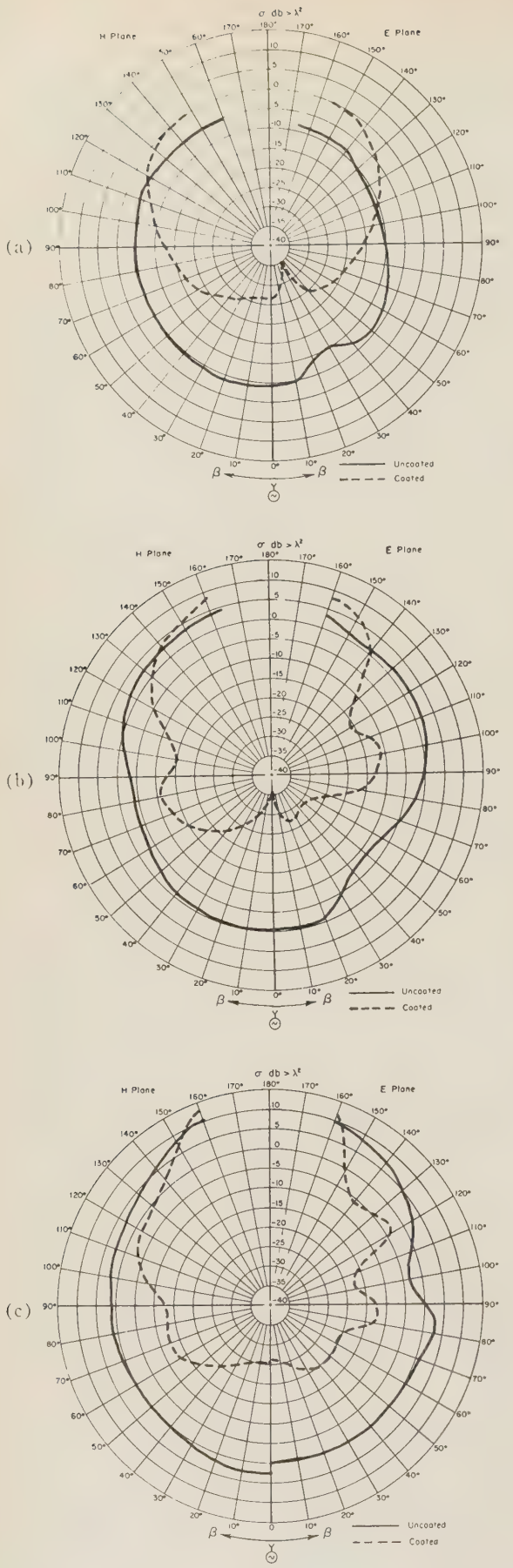


Fig. 2—Bistatic scattering cross sections of uncoated metal spheres and their coated counterparts, for vertical and horizontal polarizations of E field. $f=8.65$ kMc, $\lambda=3.47$ cm. The diameters refer to the metal core diameters. (a) 0.50-inch diameter. (b) 1.00-inch diameter. (c) 1.587-inch diameter.

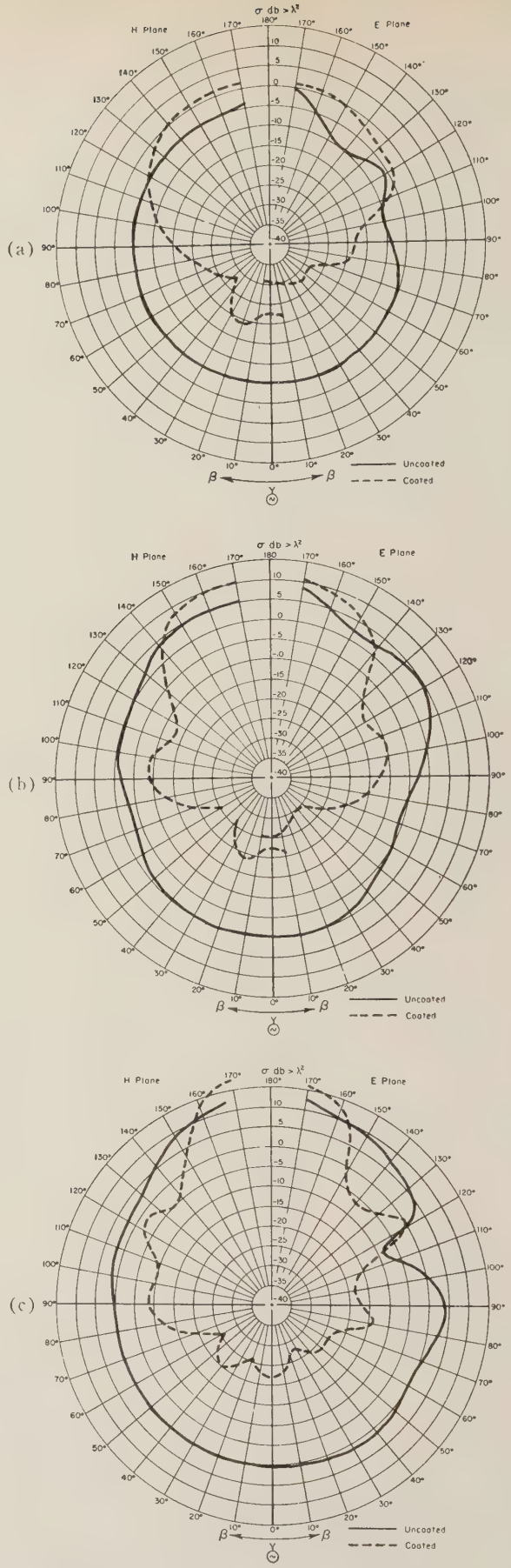


Fig. 3—Bistatic scattering cross sections of uncoated metal spheres and their coated counterparts, for vertical and horizontal polarizations of E field. $f=9.375$ kMc, $\lambda=3.2$ cm. The diameters refer to the metal core diameters. (a) 0.50-inch diameter. (b) 1.00-inch diameter. (c) 1.587-inch diameter.

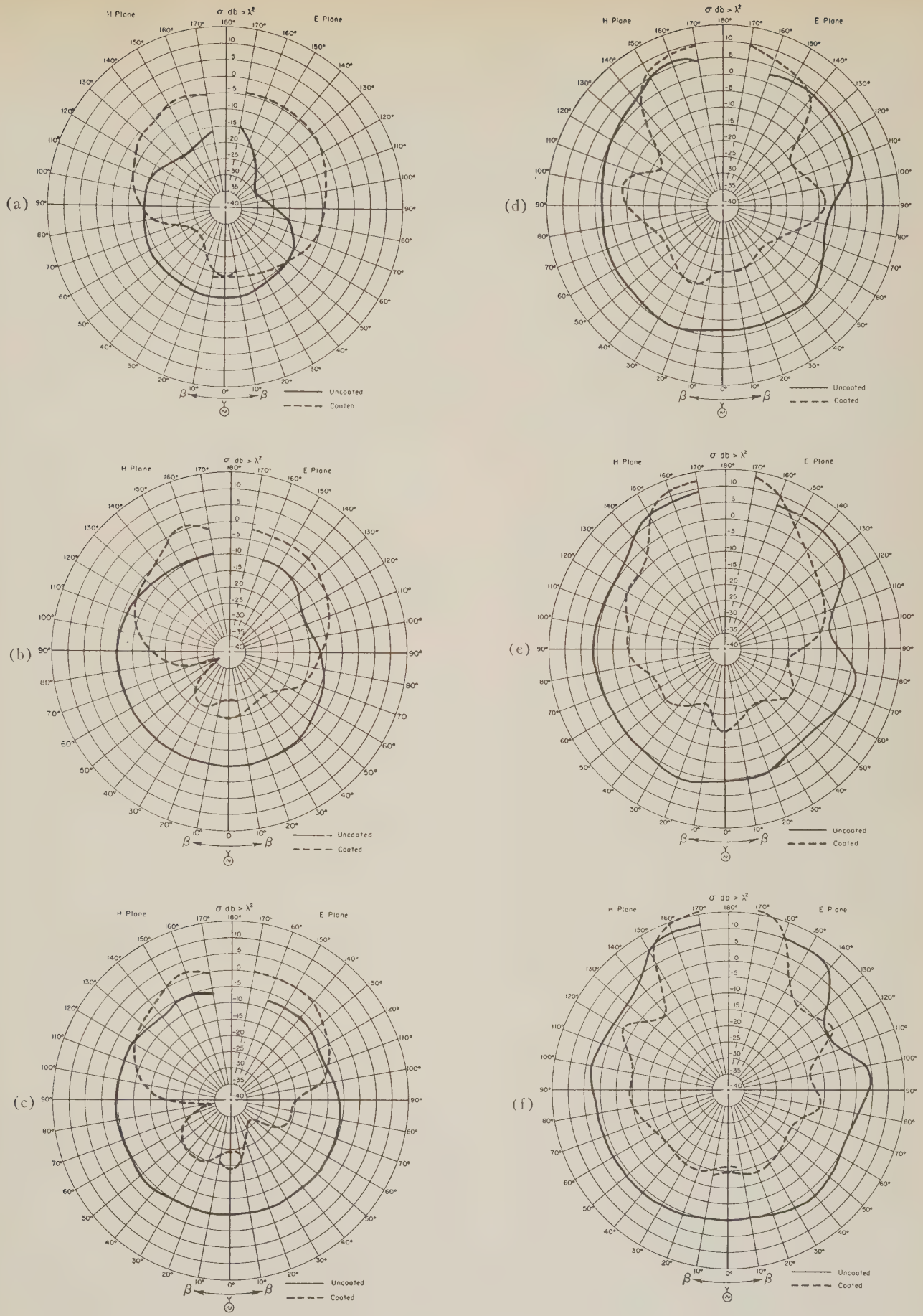


Fig. 4—Bistatic scattering cross sections of uncoated metal spheres and their coated counterparts, for vertical and horizontal polarizations of E field. $f = 10$ kMc, $\lambda = 3.0$ cm. The diameters refer to the metal core diameters. (a) 0.25-inch diameter. (b) 0.40-inch diameter. (c) 0.50-inch diameter. (d) 1.00-inch diameter. (e) 1.312-inch diameter. (f) 1.587-inch diameter.

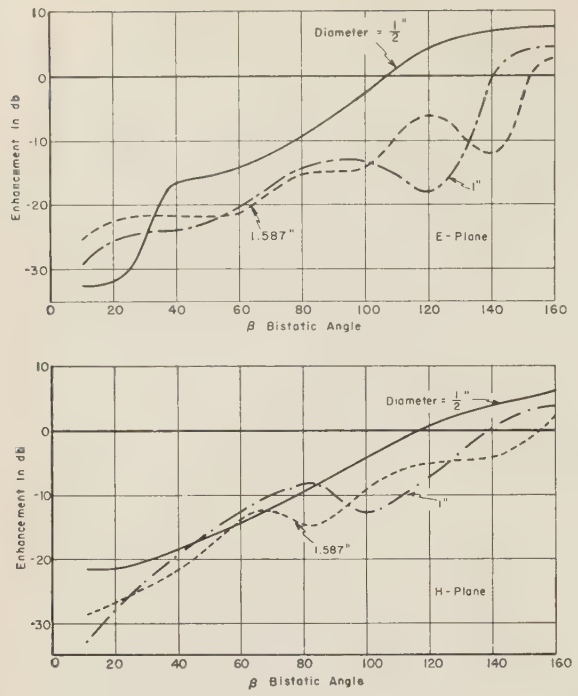


Fig. 5—Reduction or enhancement of the bistatic scattering cross sections of spheres due to absorber coating as a function of bistatic angle. $f=8.65$ kMc, $\lambda=3.47$ cm.

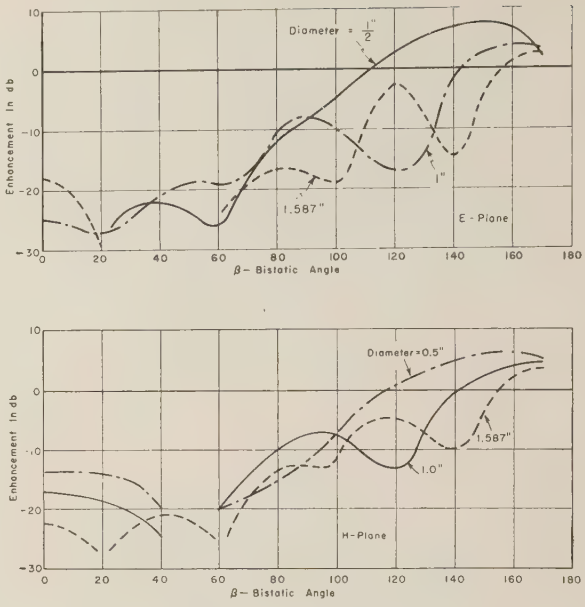


Fig. 6—Reduction or enhancement of the bistatic scattering cross sections of spheres due to absorber coating as a function of bistatic angle. $f=9.375$ kMc, $\lambda=3.2$ cm.

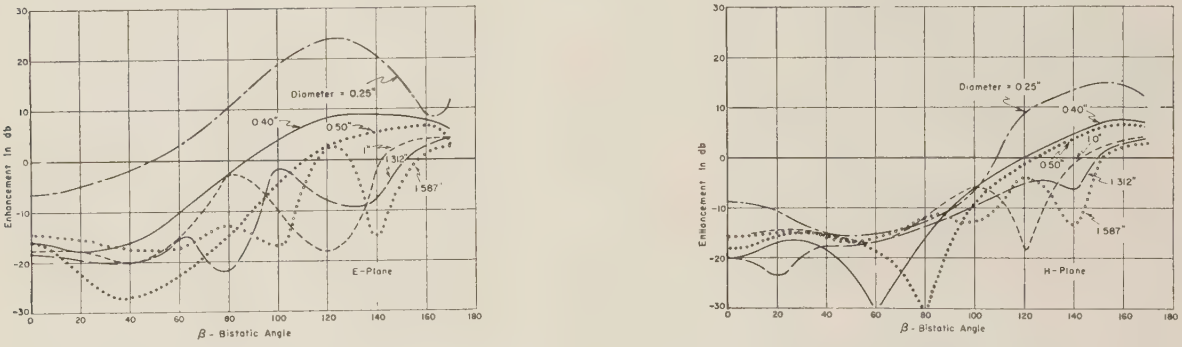


Fig. 7—Reduction or enhancement of the bistatic scattering cross sections of spheres due to absorber coating as a function of bistatic angle. $f=10$ kMc, $\lambda=3.0$ cm.

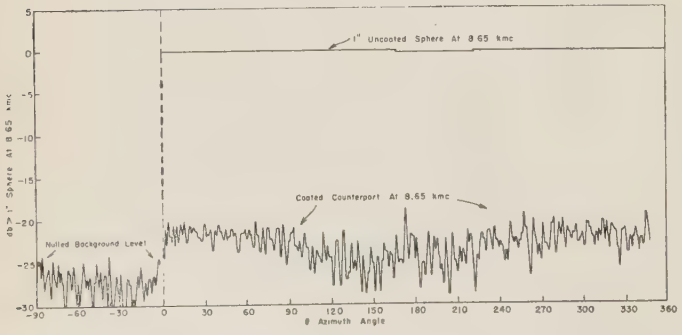


Fig. 8—An example of a data record for a 1.0-inch diameter uncoated sphere and its coated counterpart and nulled background level. $f=8.65$ kMc, $\beta=40°$, horizontal polarization.

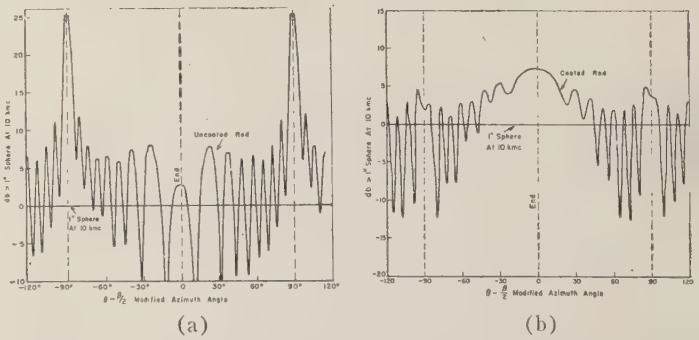


Fig. 9—An example of a data record for an uncoated 0.400-inch diameter rod and its coated counterpart. $f=10$ kMc, $\beta=40°$ vertical polarization.

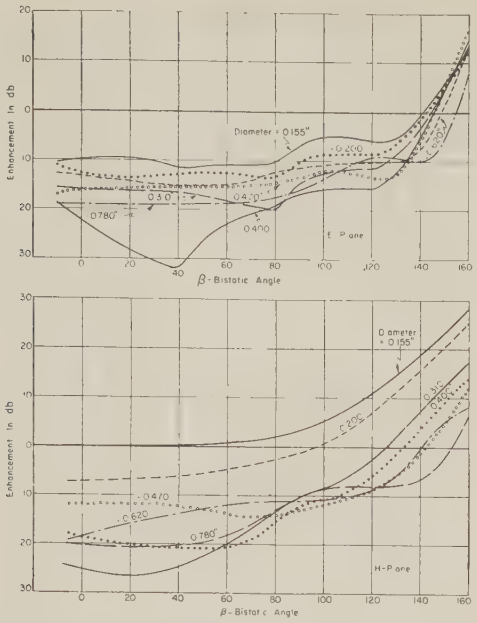


Fig. 10—Reduction or enhancement of the broadside specular reflection of rods due to absorber coating. Rod diameter is parameter. $f=10$ kMc, $\lambda=3$ cm.

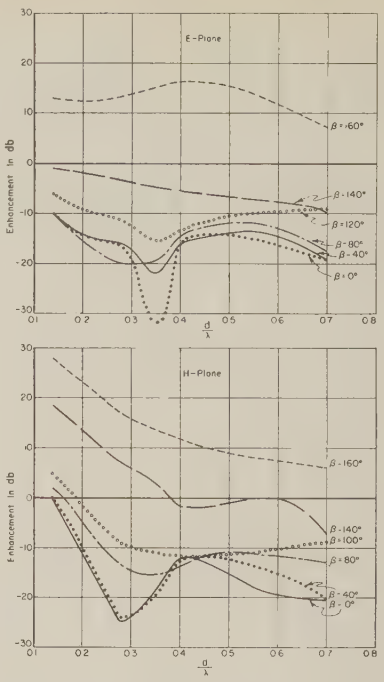
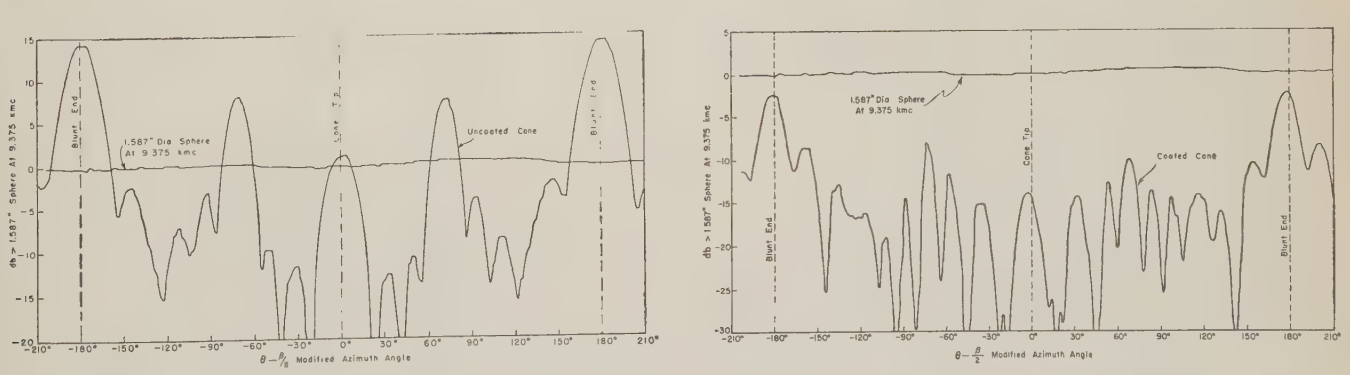


Fig. 11—Reduction or enhancement of the broadside specular reflection of rods due to absorber coating. Bistatic angle is parameter. $f=10$ kMc, $\lambda=3$ cm.

C. Cones

The bistatic scattering cross sections from a right circular cone with a slant height of 2.86 inches and an apex angle of 38.5°, and its coated counterpart, were recorded for both polarizations at 9.375 kMc. Two orientations were investigated, in which the body was rotated about a vertical axis with its axis of symmetry perpendicular to and at 45° to this vertical axis. For the interesting geometry of the cone, a more complete presentation of the data than just that of specular reflection is desirable, especially for comparison of the uncoated and coated cones. An array of azimuth patterns of scattering cross section, each for a different bistatic angle, is extremely cumbersome and cannot present an integrated picture of what is taking place. In this report the cone data are presented in the form of bistatic contour maps, in which equilevel contours of scattering cross section $\sigma(\theta, \beta)$ are plotted on rectangular coordinates of β, the bistatic angle, and $\theta-\beta/2$, the azimuth angle minus half the bistatic angle. Such maps are derived from the actual records, an example of which is shown in Fig. 12, by using discrete cross-section levels. Thus, some information is lost in the construction of the maps, but by choosing level increments and bistatic angle increments to suit the rates of change of σ with these variables, the important salient features can be shown accurately enough for the present comparison purposes.



(a) (b)

Fig. 12—An example of a data record for an uncoated and coated cone. $f=9.375$ kMc, $\beta=40°$, vertical polarization.

Contour maps of the cones, rotated about a vertical axis with their axes of symmetry perpendicular to this axis of rotation, are shown in Figs. 13 and 14, uncoated and coated respectively for horizontal polarization of the transmitted and scattered E fields.

Corresponding maps for vertical polarization are shown in Figs. 15 and 16. Similar maps are drawn in Figs. 17–20 (opposite) for the cones rotated about a vertical axis with their axes of symmetry tilted 45° from this axis of rotation.

The effects of an absorber coating on the scattering from resonant-size cones are easily discernible from the bistatic contour maps shown in Figs. 13–20. However, since the contour mapping technique has not been used extensively in the literature, some of the more salient features of the maps will be pointed out.

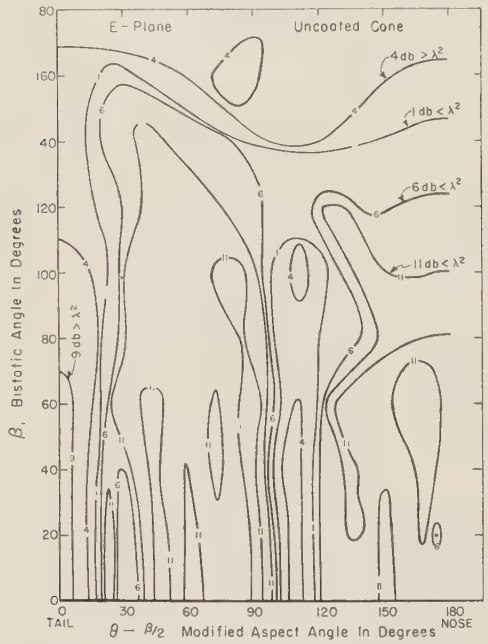


Fig. 13—Contour map for uncoated cone rotated with its longitudinal axis perpendicular to the vertical axis of rotation, horizontal polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

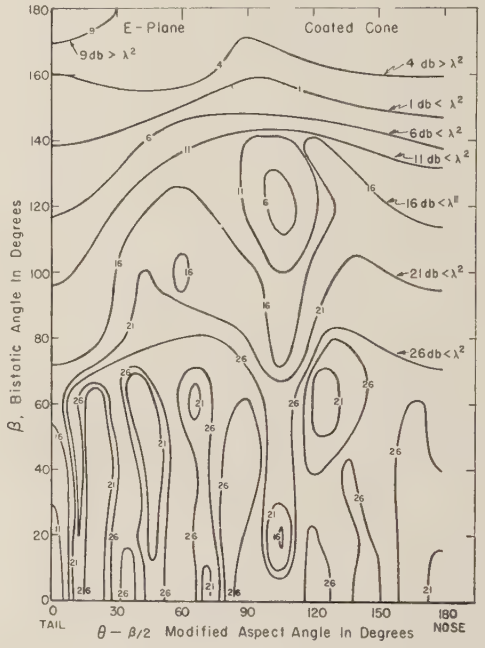


Fig. 14—Contour map for coated cone rotated with its longitudinal axis perpendicular to the vertical axis of rotation, horizontal polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

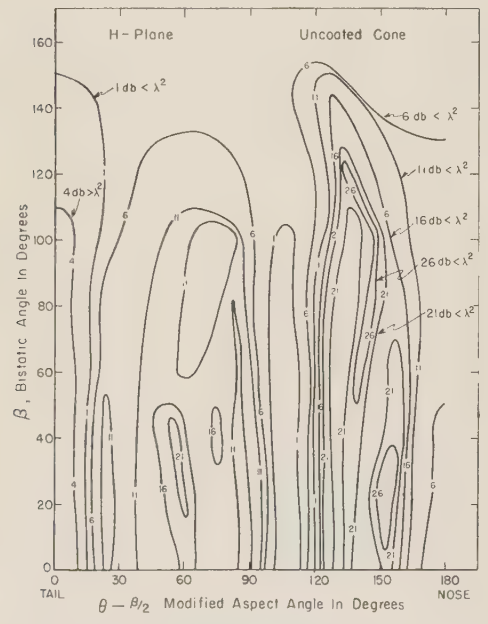


Fig. 15—Contour map for uncoated cone rotated with its longitudinal axis perpendicular to the vertical axis of rotation, vertical polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

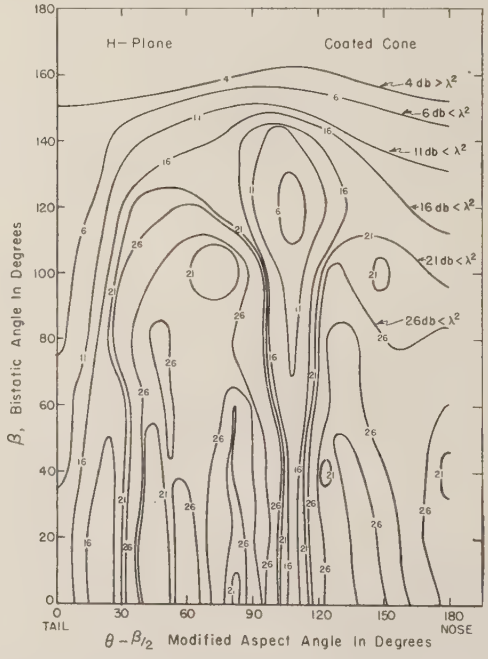


Fig. 16—Contour map for coated cone rotated with its longitudinal axis perpendicular to the vertical axis of rotation, vertical polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

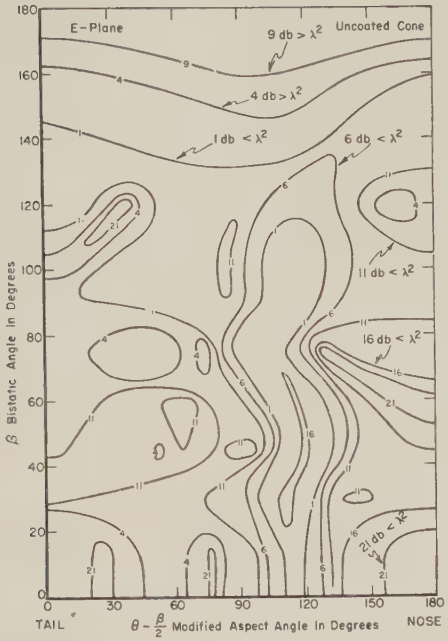


Fig. 17—Contour map for uncoated cone rotated with its longitudinal axis tilted 45° from the vertical axis of rotation, horizontal polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

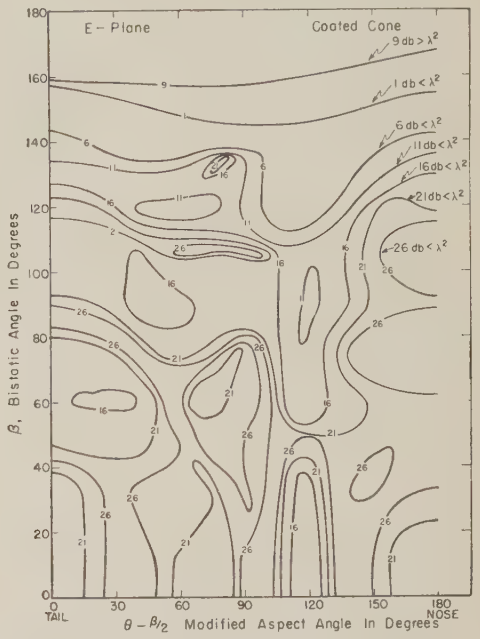


Fig. 18—Contour map for coated cone rotated with its longitudinal axis tilted 45° from the vertical axis of rotation, horizontal polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

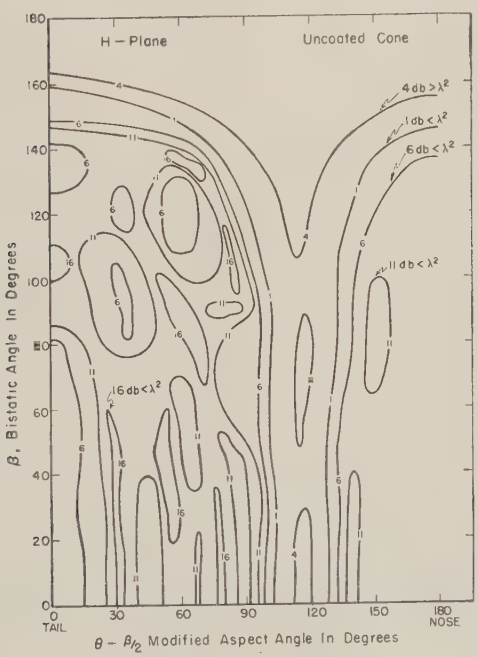


Fig. 19—Contour map for uncoated cone rotated with its longitudinal axis tilted 45° from the vertical axis of rotation, vertical polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

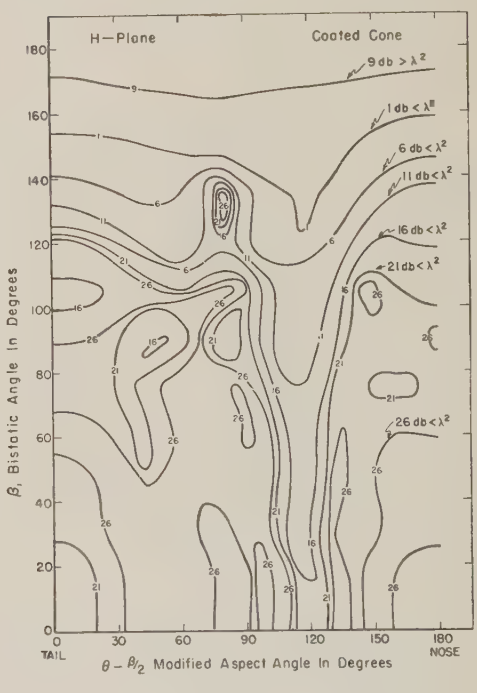


Fig. 20—Contour map for coated cone rotated with its longitudinal axis tilted 45° from the vertical axis of rotation, vertical polarization of E field, $f=9.375$ kMc, $\lambda=3.2$ cm.

The specular reflection from the base of the cone is centered at $\theta-\beta/2$ equal to zero. From Figs. 13 and 14, then, as an example, it is noted that for bistatic angles of less than 100° the base specular reflection is reduced at least 20 db by the absorber coating. Specular reflection from the side of the cone is centered at approximately $\theta-\beta/2$ equal to 108°, as the contour ridge in Fig. 13 clearly demonstrates; and again for bistatic angles of less than 100°, at least a 20-db reduction is noted. Similar comparisons may be made of the scattering at any aspect of the cone for any range of bistatic angles. For large bistatic angles, the contour maps reveal an enhancement of the scattering for the coated cones. The magnitude of the enhancement is not so readily obtained, since forward scatter measurements were not made, and that portion of the contour map is correspondingly sketchy. For bistatic angles of greater than 160°, the contours should be taken only as approximations.

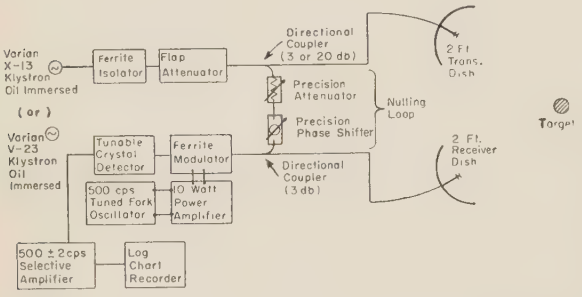


Fig. 21—Schematic diagram of the microwave equipment used for this paper.

Conclusions

In each test performed on bodies in the resonant region experiments show that the absorber coating is effective in reducing scattered energy in the back hemisphere but that in the forward hemisphere scattered energy is increased. It appears that the coated bodies act similarly to lossy lenses which transform some of the energy extracted from the incident wave into heat and reradiate most of the remaining energy into a forward cone. As the body size (in wavelengths) increases, the cone of radiation in the forward direction, within which the scattering from the coated body is greater than that from its uncoated counterpart, becomes narrower.[4]

[4] R. E. Hiatt, K. M. Siegel, and H. Weil, "Forward scattering by coated objects illuminated by short wavelength radar," Proc. IRE, vol. 48, pp. 1630–1635; September, 1960.

Appendix

A schematic diagram of the microwave equipment used to obtain the measured data in this paper is shown in Fig. 21. The system was designed so that either a 250-mw Varian X-13 or a 5-watt Varian V-23 klystron could be used, thus providing for low-power variable frequency or high-power fixed frequency operation. Ferrite modulation was employed in the receiver link to minimize frequency modulation of the source, which is necessary in a null-loop system.

The physical arrangement of the darkroom is shown in Fig. 22. The ceiling and that part of the floor under the target were covered with hairflex. The walls of the room were covered with a combination of hairflex and Plessey, with most of the Plessey located normal to the line of sight from the transmitter. In addition, three

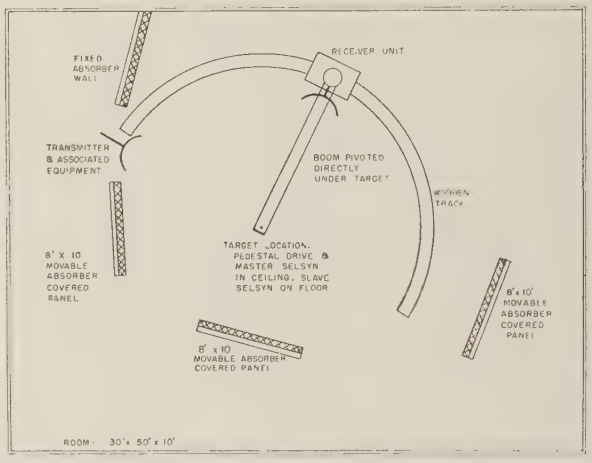


Fig. 22—Physical arrangement of the microwave darkroom.

movable panels of Plessey could be oriented to minimize the background for any bistatic angle.

All measurements presented in this report were made at a range of 15 feet using 2-foot parabolic dishes. The phase and amplitude distributions at the target did not vary more than 22° and 1 db, respectively, over an eight-inch length, and were constant within 10° and $\frac{1}{2}$ db over the targets themselves. Bistatic angles of 165° were measured for all targets, and in some cases 170° angles were possible.

Acknowledgment

The authors wish to acknowledge the helpful discussions of W. Emerson and Dr. R. Wright at the Naval Research Laboratory, who provided us with the targets discussed in this paper. The help of R. Evans, who recorded most of the data, is also appreciated.

IRE Standards on Video Techniques: Definitions of Terms Relating to Television, 1961*

61 IRE 23.S1

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* Approved by the IRE Standards Committee, July 10, 1958. At the request of Committee 23, publication was withheld until additional terms had been standardized. This Standard includes revisions of the 1948 list of definitions. However, the revisions contained in 55 IRE 23.S1 are not repeated. Reprints of this Standard 61 IRE 23.S1 may be purchased while available from the Institute of Radio Engineers, 1 East 79th Street, New York, N. Y., at $0.50 per copy. A 20 per cent discount will be allowed for 100 or more copies mailed to one address.

Aspect Ratio. The ratio of the frame width to the frame height.

Brightness Channel (Deprecated). See *Luminance Channel.*

Camera Tube. A tube for conversion of an optical image into an electrical signal by a scanning process.

Chrominance Channel. In a color television system, any path which is intended to carry the chrominance signal.

Chrominance Channel Bandwidth. The bandwidth of the path intended to carry the chrominance signal.

Chrominance Signal Component. A signal resulting from suppressed carrier modulation of a chrominance subcarrier voltage at a specified phase, by a chrominance primary signal.

Color Sync Signal. A signal used to establish and to maintain the same color relationships that are transmitted.

Note: In the FCC Rules covering Radio Broadcast Services, Part 3, the color sync signal consists of a sequence of color bursts which is continuous except for a specified time interval during the vertical interval, each burst occurring on the back porch.

Contrast Ratio. The ratio of the maximum to the minimum luminance values in a television picture or a portion thereof.

Note: Generally the entire area of the picture is implied but smaller areas may be specified as in "detail contrast."

Deflection Yoke. An assembly of one or more coils, whose magnetic field deflects an electron beam.

DC Restoration. The re-establishment by a sampling process of the dc and the low-frequency components of a video signal which have been suppressed by ac transmission.

DC Restorer. A device for re-establishing by a sampling process the dc and low-frequency components of a video signal which have been suppressed by ac transmission.

Note: The sampling process can be accomplished either by the video signal itself or by external pulses.

DC Transmission. A form of transmission in which the dc component of the video signal is transmitted.

Note: In an amplitude-modulated signal with dc transmission, the black level is represented always by the same value of envelope. In a frequency-modulated signal with dc transmission, the black level is represented always by the same value of the instantaneous frequency.

Flyback. The rapid return of the beam in the direction opposite to that used for scanning.

Geometric Distortion. The displacement of elements in the reproduced picture from the correct relative positions in the perspective plane projection of the original scene.

Gray Scale. An optical pattern in discrete steps between light and dark.

Horizontal Hold Control. A synchronization control which varies the free-running period of the horizontal deflection oscillator.

Interlace Factor. A measure of the degree of interlace of nominally interlaced fields.

Note: In a two-to-one interlaced raster, the interlace factor is the ratio of the smaller of two distances between the centers of adjacent scanned lines to one-half the distance between centers of sequentially scanned lines at a specified point.

Jitter. Abrupt spurious deviations in a signal or in the position of a repeated display of an observed quantity.

Limiting Resolution. In television, a measure of resolution usually expressed in terms of the maximum number of lines per picture height discriminated on a test chart.

Note: For a number of lines N (alternate black and white lines) the width of each line is $1/N$ times the picture height.

Linearity Control. A control to adjust the variation of scanning speed during the trace interval to correct geometric distortion.

Luminance Channel. In a color television system, any path which is intended to carry the luminance signal.

Luminance Channel Bandwidth. The bandwidth of the path intended to carry the luminance signal.

Monochrome Channel. Any path which is intended to carry the monochrome signal.

Monochrome Channel Bandwidth. The bandwidth of the path intended to carry the monochrome signal.

Number of Scanning Lines. The ratio of line frequency to frame frequency.

Nominal Line Pitch. The average separation between centers of adjacent lines forming a raster.

Pairing. In scanning, the condition in which lines appear in groups of two instead of equally spaced.

Picture Tube. A cathode-ray tube used to produce a television image.

Progressive Scanning. A rectilinear process in which adjacent lines are scanned in succession.

Overshoot. Overshoot is the initial transient response to a unidirectional change in input, which exceeds the steady-state response. (ASA Definition 65.02.085.)

Raster. A predetermined pattern of scanning lines which provides substantially uniform coverage of an area.

Rectilinear Scanning. The process of scanning an area in a predetermined sequence of straight parallel scanning lines.

Resolution in Television. In television, a measure of ability to delineate picture detail.

Note: Resolution is usually expressed in terms of a number of lines discriminated on a test chart. For a number of lines N (normally alternate black and white lines) the width of each line is $1/N$ times the picture height.

Resolution Wedge. A narrow-angle wedge-shaped pattern calibrated for the measurement of resolution and composed of alternate contrasting strips which gradually converge and taper individually to preserve equal widths along any given line at right angles to the axis of the wedge.

Note: Alternate strips may be black and white of maximum contrast or strips of different colors.

Return Interval. The interval corresponding to the direction of sweep not used for delineation.

Retrace Interval. See *Return Interval.* This item is deprecated.

Return Trace. The path of the scanning spot during the return interval.

Sawtooth Wave. A periodic wave whose instantaneous value varies substantially linearly with time between two values, the interval required for one direction of progress being longer than that for the other.

Scanning Line. A single continuous narrow strip which is determined by the scanning process.

Scanning Linearity. A measure of the uniformity of scanning speed during the unblanked trace interval.

Scanning Speed. The time rate of linear displacement of the scanning spot.

Staircase Signal. A waveform consisting of a series of discrete steps resembling a staircase.

Note: The staircase signal is the electrical equivalent of a gray scale. The heights of the steps may vary, monotonically increasing or decreasing.

Step Wedge (Deprecated). See *Gray Scale.*

Spot Wobble. A process wherein a scanning spot is given a small periodic motion transverse to the scanning lines at a frequency above the picture signal spectrum.

Trace Interval. The interval corresponding to the direction of sweep used for delineation.

Undershoot. Undershoot is the initial transient response to a unidirectional change in input, which precedes the main transition and is opposite in sense.

Vertical Hold Control. A synchronization control which varies the free running period of the vertical deflection oscillator.

The Elimination of Intersymbol Interference by Input Signal Shaping*

I. GERST† AND J. DIAMOND‡

Summary—**Given a time-invariant linear system, the problem of determining those input wave shapes which result in outputs that are zero after a finite time (pulse outputs) is studied. Conditions characterizing these input, pulse-output pairs associated with a linear system are given in terms of their Laplace transforms and the system function. These conditions are then applied in two cases: 1) the general lumped-parameter system, and 2) the general transmission line, to determine classes of suitable input waves for each of these systems. It is shown that the input itself may be taken to be a pulse for all the systems of case 1, and in case 2 for the distortionless infinite line and the general finite line. Furthermore, in case 1 and also for the general RC finite line, the lengths of the associated input and output pulses can be made arbitrarily small.**

I. Introduction

WHEN a pulse, defined here as a waveform which exists in a time interval and vanishes outside the interval, is passed through a linear system, the output generally has a tail or asymptote which stretches out to infinity. This tail makes more difficult the resolution of succeeding pulses, especially in the presence of noise, and so limits the minimum spacing which may be used between pulses. Thus any technique which reduces the tail increases the possible pulse rate, at least in a purely binary system in which only the presence or absence of a pulse conveys information, not pulse shape (leading edge, etc.).

One possible technique is design of the system to reduce the tail. This is the transient synthesis problem and is not the approach we propose.

Rather, for a given system function $F(s)$, we consider the effect of the input wave shape $e_i(t)$ (not necessarily a pulse) on the output tail.[1] Specifically, in Sections II and III, we formulate conditions on $e_i(t)$ under which the output tail can be *eliminated completely.* Then, in Sections IV and V, we show that these conditions can be satisfied, respectively, in the case of a lumped-element constant parameter system and for the general transmission line, finite or infinite; and we give various methods for constructing the requisite inputs. Thus it follows, surprisingly, that by proper choice of the input

* Received by the IRE, September 19, 1960; revised manuscript received, March 7, 1961. The research reported in this paper was performed at RCA for IT&T Communications Systems, Paramus, N. J., in connection with the Air Force 480-L program under Contract No. AF-30(635)-12857.

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[1] Another approach is used by L. A. MacColl (U. S. Patent 2,056,284; 1936). He proposed eliminating intersymbol interference by inserting corrections at the receiver, the transmitted wave shape and the transient response of the system being known.

wave the outputs of the aforementioned systems can be made pulses.

Furthermore, in the lumped parameter case the input wave may also be taken as a pulse of the same length as the output, and this length may be made as narrow as desired. As regards the transmission line, a pulse input is possible in the cases of the distortionless infinite line and the general finite line. In the latter case, arbitrarily small input and output pulse lengths may be attained for the RC line.

II. The Finite Laplace Transform

Consider the time-invariant linear system of Fig. 1 and assume that $e_i(t)$ and $e_o(t)$ have Laplace transforms $E_i(s)$ and $E_o(s)$ respectively, so that, with zero initial conditions, we may write

$$E_o(s) = F(s)E_i(s). \tag{1}$$

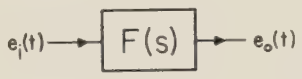


Fig. 1.

We inquire into the possibility of choosing an input $e_i(t)$, such that the output $e_o(t)$ is a function which is identically zero for $t>a$, $a>0$.

A function $g(t)$ with $g(t)\equiv 0$ for $t<0$ and for $t>a$, $a>0$, will be called a pulse of length a. Thus we require $e_o(t)$ to be a pulse of length a, and then it follows that integral defining the Laplace transform of $e_o(t)$ acquires a finite upper limit, so that

$$E_o(s) = \int_0^a e_o(t)e^{-st}dt.$$

Such a transform will be called a *finite Laplace transform* of length a.

Referring now to (1), it is seen that, given the system function $F(s)$, the problem of determining an input $e_i(t)$ yielding a pulse output $e_o(t)$ is reduced to finding a Laplace transform $E_i(s)$ for which $F(s)E_i(s)$ is a *finite* Laplace transform.

At this point, in order to be able to proceed further, we must make use of certain results concerning the finite Laplace transform

$$G(s) = \int_0^a g(t)e^{-st}dt. \tag{2}$$

These will now be considered briefly. As a basis for our discussion, we will assume a development of Laplace transform theory along the lines of Doetsch's[2] recent treatment and will refer to this work whenever necessary for further amplification.

As is well known, a finite integral such as the one in (2) converges for all complex s, defining an analytic function with no singularities in the finite plane, *i.e.*, an entire function. However, this condition on $G(s)$ alone is not sufficient to insure that $g(t)$ be a pulse. For example, the Laplace transform of e^{-t^2}, $t\geq 0$, a nonpulse, is also an entire function.

A theorem giving conditions which characterize the Laplace transform of a pulse has been proved by Doetsch[3] and in our terminology may be stated as follows (here $s=x+iy$, x, y real and C is a positive constant):

Theorem 1

Necessary and sufficient conditions that a Laplace transform $G(s)$ be a finite Laplace transform of length "a" are

a) *$G(s)$ is an entire function,*
b) $|G(x+iy)| \leq C$, *for* $x\geq 0$,
c) $|G(x+iy)| \leq Ce^{ax}$, *for* $x<0$.

The additional conditions b and c require respectively that $G(s)$ be bounded in the right-half plane, and that $e^{as}G(s)$ be bounded in the left-half plane.

Theorem 1 is quite general in that it permits pulses $g(t)$ which are unbounded at a finite number of points in $(0, a)$, as long as $g(t)$ is absolutely integrable at these points. A classic example of this is the pulse $g(t)$ of length 2, defined as

$$g(t) = \frac{1}{\sqrt{t(2-t)}}, \qquad 0<t<2$$
$$= 0, \text{ elsewhere,}$$

which is unbounded at $t=0$, $t=2$ and for which the corresponding finite Laplace transform is $\pi J_0(is)$ [J_0 is the Bessel function of zero order].

Theorem 1 can be modified so that it applies to more restricted classes of pulses which have additional properties of interest for the applications. We mention one of these modifications which is useful in constructing finite Laplace transforms whose corresponding pulses are differentiable.

Theorem 2

Necessary and sufficient conditions that a Laplace transform $G(s)$ be a finite Laplace transform of length "a" corresponding to a pulse $g(t)$ having a generalized nth derivative[4] in the interval $(0, a)$ which is Laplace transformable and for which $g(0^+)=g'(0^+)=\cdots=g^{(n-1)}(0^+)=0=g(a^-)=g'(a^-)=\cdots g^{(n-1)}(a^-)$, *are*

a) *$G(s)$ is an entire function,*
b) *$s^nG(s)$ is a finite Laplace transform.*

By properly assigning the values of the derivatives at the end points of the interval[5] $(0, a)$, the pulse $g(t)$ of

[2] G. Doetsch, "Theorie und Anwendung der Laplace Transformation," Birkhauser, Basel, Switzerland; 1958.

[3] *Ibid.*, p. 177.

[4] A function $f(t)$ is said to have a generalized first derivative $f^{[1]}(t)$ if $f(t)=f(0)+\int_0^t f^{[1]}(t)dt$. Higher-order generalized derivatives $f^{[n]}(t)$ are defined in an analogous manner, cf., *ibid.*, pp. 49–51.

[5] *Ibid.*, p. 51.

Theorem 2 may be described as having continuous derivatives up to order $(n-1)$ and a generalized nth derivative, for all t. This alternative description of $g(t)$ in Theorem 2 will be used in the sequel.

The proof of Theorem 2 follows readily from the fact that under the given conditions on $g(t)$, $\mathcal{L}[g^{[n]}(t)] = s^n G(s)$, and this argument can be reversed. The details will be omitted here.

We now prove the following result which exhibits explicitly a class of finite Laplace transforms of common occurrence.

Theorem 3

If $P_i(s)$, $(i=1, 2, \cdots, k)$ and $D(s)$ *are polynomials in* s *with the* $P_i(s)$ *of lower degree than* $D(s)$, *and if* a_i, $(i=1, 2, \cdots, k)$ are *non-negative real numbers, then the function*

$$G(s) = \frac{1}{D(s)} \cdot \sum_{i=1}^{k} e^{-a_i s} P_i(s)$$

is a finite Laplace transform of length $a = \max a_i$, $(i=1, 2, \cdots, k)$ *if, and only if, it is entire.*

Proof:

By Theorem 1, it is necessary that $G(s)$ be entire. Conversely, suppose that $G(s)$ is entire. Since $|e^{-a_i s}| \leq 1$ for Re $(s) \geq 0$, and since by hypothesis it follows that $P_i(s)/D(s) \to 0$ as $s \to \infty$, we conclude that $G(s)$ is bounded in Re $(s) \geq 0$. Similarly, $e^{as}G(s)$ is bounded in Re $(s) < 0$, since, if s is replaced by $-s$, this function is of the same form as the original $G(s)$. Finally, as is well known, $G(s)$ is a Laplace transform. Thus all the conditions of Theorem 1 are satisfied and it follows that $G(s)$ is a finite Laplace transform. This concludes the proof of Theorem 3.

By admitting impulses of any order as part of the pulse function, Theorem 3 can be extended to cover the case when the $P_i(s)$ are not of lower degree than $D(s)$.

As a final observation, we mention that it follows directly from Theorem 1 that the class of finite Laplace transforms is closed under addition and multiplication. More precisely, we have that: 1) The sum of two finite Laplace transforms of lengths a and b, respectively, is a finite Laplace transform of length $c \leq \max(a, b)$; 2) The product of two finite Laplace transforms[6] of lengths a and b, respectively, is a finite Laplace transform of length $c \leq (a+b)$.

III. The Basic Conditions

We come back now to the question, raised in Section II, of determining a Laplace transform $E_i(s)$ such that $F(s)E_i(s)$ is a *finite* Laplace transform. We see, in the light of Theorem 1, that $E_i(s)$ must be chosen so that the following *basic conditions* hold:

a) $F(s)E_i(s)$ is a Laplace transform;
b) $F(s)E_i(s)$ is an entire function;
c) $F(s)E_i(s)$ satisfies the boundedness conditions b and c of Theorem 1.

Conversely, if these conditions are satisfied $F(s)E_i(s)$ will be a finite Laplace transform.

In the remaining sections of this paper, it will be shown that input transforms $E_i(s)$ exist for which these conditions can be met when $F(s)$ is the system function of a lumped element network or of a transmission line. By way of orientation, we conclude this section by making several remarks relevant to the fulfillment of the basic conditions.

The verification of condition c of Section III will seldom be necessary. In most simple situations where it is possible to obtain an inverse easily, it will generally suffice to establish conditions a and b, since explicit inversion will usually indicate whether or not a pulse is present.

If $F(s)$ has poles, then b requires that these be cancelled by zeros of $E_i(s)$. Many solutions can be found simply by constructing $E_i(s)$ with the requisite zeros. $E_i(s)$ itself may have poles, but only if these poles are cancelled by zeros of $F(s)$. In that case, the input has a tail but the output has none. If the input is also to be a pulse then evidently conditions a–c must be satisfied with $E_i(s)$ a *finite* Laplace transform.

If $E_i(s)$ and $E_o(s)$ correspond to a solution of (1) with $E_o(s)$ a finite Laplace transform, other solutions can be generated by multiplying both sides of (1) by any finite Laplace transform $G(s)$, giving a new input $E_i(s)G(s)$ and a new output $E_o(s)G(s)$. In the time domain this means that the new input is $e_i(t)*g(t)$ and the new output $e_o(t)*g(t)$, where $*$ indicates convolution.

IV. The Lumped-Element Constant Parameter System

In this section, we restrict $F(s)$ to be the system function of a lumped-element constant parameter network. Then $F(s)$ is a rational function which may be written in any of the forms

$$F(s) = \frac{N(s)}{D(s)} = \frac{\sum_{i=0}^{m} k_i s^i}{\sum_{i=0}^{n} h_i s^i} = \frac{N(s)}{\prod_{i=1}^{n} (s - \gamma_i)} \cdot \qquad (3)$$

Here $N(s)$ and $D(s)$ are real polynomials with no common factor, and we assume[7] that $m \leq n$, $n \geq 1$, and $h_n = 1$.

We will show that: *For each fixed* $F(s)$ *of the form* (3), *there exist input pulses of arbitrary length* a, *such that the corresponding outputs of the system are pulses of the same length* a. In this result, the fact that the pulse

[6] For this rule to hold in general, the pulses corresponding to the transforms are allowed to be improperly integrable only at $t=0$. *Ibid.*, pp. 54–55.

[7] The restriction $m \leq n$ is made for simplicity. The procedure to be used when $m > n$ will be evident from the discussion in this section.

length is arbitrary and hence can be made arbitrarily small could be of some interest for the applications.

As a consequence of our discussion in Section II, the above statement will be proved if we construct a pair of finite Laplace transforms $E_i(s)$, $E_o(s)$ $(=F(s)E_i(s))$ of arbitrary length a. We give two methods for doing this, the first of which is concerned with the transform domain alone, while the second considers certain mutual relationships of time and transform domains.

A. Method of Zero Insertion in Transform Domain

Consider the entire function

$$E_i(s) = \frac{1 - e^{-\epsilon s}}{s} \cdot \prod_{j=1}^{n} [1 - e^{-\epsilon(s-\gamma_j)}], \tag{4}$$

where ϵ is an arbitrary positive number and the γ_j are as in (3). Then by Theorem 3 of Section II, $E_i(s)$ is a finite Laplace transform of length $(n+1)\epsilon$. This is the desired input transform.[8]

Since $E_i(\gamma_j)=0$, $F(s)E_i(s)$ is an entire function and, by Theorem 3 of Section II, is a finite Laplace transform of length $(n+1)\epsilon$. With $a=(n+1)\epsilon$, this proves the statement made at the beginning of this section, since n is fixed.

The inversion of $E_i(s)$ and $E_o(s)=F(s)E_i(s)$ to get $e_i(t)$ and $e_o(t)$ presents no difficulty and will be omitted, particularly since an alternative solution of the problem is given in Section IV-B.

Several observations regarding the method given above follow:

1) Instead of the factor $(1-e^{-\epsilon s})/s$ in (4), we can use any finite Laplace transform $G(s)$ of the form given in Theorem 3 of Section II.
2) If the input $e_i(t)$ is not required to be a pulse, we can multiply $E_i(s)$ in (4) by $1/\Pi(s-\delta_i)$ where the δ_i range over some or all of the zeros[9] of $N(s)$, and still get a pulse output.
3) The input pulse defined by (4) will, in general, be discontinuous within the interval $(0, a)$ as well as at the end points. If one desires an input pulse which shall be of class C^n for all t (*i.e.*, have continuous derivatives up to order n for all t, so that, in particular, these derivatives are zero at 0 and a), then (4) can easily be modified to provide such an input. Namely, by Theorem 3 of Section II, the function $E_1(s)=E_i(s)\cdot(1-e^{-\epsilon s})^{n+1}/s^{n+1}$, with $E_i(s)$ as in (4), is a finite Laplace transform which by Theorem 2 of Section II corresponds to an input pulse having the desired differentiability properties. The output transform $E_o(s)=F(s)E_i(s)$ is again of the form given in Theorem 3 and so corresponds to a pulse.

[8] The pulse $e_i(t)$ corresponding to $E_i(s)$ is a real function, since the presence of complex conjugate γ_j in (4) will result in $E_i(s)$ having real coefficients when the product in (4) is multiplied out and $E_i(s)$ is expressed in the form given by Theorem 3 of Section II.

[9] Complex zeros are, of course, to be taken in conjugate pairs.

B. Direct Method in Time Domain

We now consider a second method of obtaining pulse outputs and associated pulse inputs, when $F(s)$ is the system function given in (3). The development here will be largely heuristic. A formal proof of the fundamental representations (5) and (6) is given in Appendix I.

From (3) and (1) we have

$$E_i(s)\frac{N(s)}{D(s)} = E_o(s).$$

There is a temptation to write $E_i(s)=D(s)$, thus removing all the poles of $F(s)$. The trouble is that the resulting $e_i(t)$ will be a sum of higher-order impulses which we do not consider an acceptable solution. But it must be possible to write

$$E_i(s) = E_1(s)D(s),$$
$$E_o(s) = E_1(s)N(s),$$

where $E_1(s)$ is entire, because $E_i(s)$ must contain all the factors of $D(s)$. Thus,

$$E_i(s) = h_0E_1(s) + h_1sE_1(s) + \cdots + h_ns^nE_1(s)$$

and, formally, an inversion of this equation leads to

$$e_i(t) = h_0e_1(t) + h_1e_1'(t) + \cdots + h_ne_1^{(n)}(t). \tag{5}$$

Similarly, we get

$$e_o(t) = k_0e_1(t) + k_1e_1'(t) + \cdots + k_me_1^{(m)}(t). \tag{6}$$

It will be shown in Appendix I that (5) and (6) give a representation for all input and output pulse pairs associated with the system function $F(s)$. In these equations $e_1(t)$ is any pulse of length a having a generalized nth derivative for all t, but is otherwise arbitrary.

V. Transmission Lines

In this section, we consider the determination of input and pulse-output pairs for system functions $F(s)$, which are associated with uniform transmission lines having lumped-element terminations. We shall discuss only the case of $F(s)$ as a voltage transfer ratio, since the other cases are treated in an analogous manner.

Then, for the general infinite line with source impedance Z_0 and characteristic impedance Z_c, we have

$$F(s) = \frac{Z_c}{Z_c + Z_0}e^{-qx}; \tag{7}$$

and for the finite line of length l with, in addition, a load impedance Z_t, the voltage transfer function with respect to the end of the line is [10]

$$F(s) = \frac{Z_cZ_t}{(Z_c^2 + Z_0Z_t)\sinh ql + Z_c(Z_0 + Z_t)\cosh ql}. \tag{8}$$

[10] *Cf.*, E. Weber, "Linear Transient Analysis," John Wiley and Sons, Inc., New York, N. Y., vol. 2, pp. 279, 379, 400; 1956.

Here

$$q = \sqrt{\alpha s^2 + \beta s + \gamma},$$

$$Z_c = \frac{q}{G + sC},$$

and $\alpha = LC$, $\beta = LG + RC$, $\gamma = RG$ where L, G, R, C are the constants of the line.

We assume now that Z_0 and Z_t are lumped-element impedances. Then, expressing Z_0 and Z_t as quotients of polynomials, *viz.*, $Z_0 = N_0/D_0$, $Z_t = N_t/D_t$, (7) and (8) become

$$F(s) = \frac{P_1(s)}{P_1(s) + \dfrac{P_2(s)}{q}} e^{-qx}, \qquad x > 0 \tag{9}$$

and

$$F(s) = \frac{P_3(s)}{P_4(s) \cosh ql + P_5(s) \dfrac{\sinh ql}{ql}}, \tag{10}$$

respectively. Here the $P_i(s)$, $(i = 1, \cdots, 5)$ are polynomials which are defined by

$$P_1 = D_0, \qquad P_2 = (G + sC)N_0,$$
$$P_3 = N_t D_0 (G + sC), \quad P_4 = (N_t D_0 + N_0 D_t)(G + sC),$$
$$P_5 = q^2 D_0 D_t + N_0 N_t (G + sC)^2.$$

For simplicity, it is convenient to normalize the expressions in (9) and (10).

As is well known, q may be transformed into the form $q = \sqrt{s^2 - \lambda^2}$, $\lambda^2 \geq 0$ or $q = \sqrt{s}$ according as $\alpha \neq 0$ or $\alpha = 0$ respectively (*i.e.*, according as wave propagation or diffusion is present), and simultaneously x and l may each be taken to be unity in (9) and (10), respectively. These normalizations can be achieved by replacing s successively by $s + c_1$, and $c_2 s$, where c_1 and c_2 are suitably chosen positive constants. As a result of these operations, polynomials in s remain polynomials in the transform domain, while pulses corresponding to finite Laplace transforms remain pulses in the time domain. We may therefore, without loss of generality, suppose that (9) and (10) are already in normal form with q as above and $x = l = 1$.

In proceeding to determine suitable inputs associated with the given system functions (9) and (10), it is immediately evident that we are faced with different situations in these two cases. For the infinite line [see (9)], $F(s)$ will in general have branch points, and the relation $E_o(s) = F(s)E_i(s)$ with $E_o(s)$ a finite Laplace transform cannot be satisfied if $E_i(s)$ is entire. Thus the inputs, $e_i(t)$, cannot, in general, be pulses. The only exception is the distortionless line when $\lambda = 0$ and $q = s$.

On the other hand, the system function $F(s)$ of (10) for the finite line is a meromorphic function of s and thus input pulses are possible. We will show that this possibility actually may be realized.

Since the rationale of our method has been detailed in the previous sections, we now restrict ourselves simply to listing one family of inputs leading to pulse outputs for each of the cases which must be considered. The representation of these inputs is analogous to that used in Section III-B for the lumped-parameter case. We do not go into the question of totality of solutions here.

A. Infinite Line:

1) $\alpha = LC \neq 0$; $F(s)$ given by (9) with $q = \sqrt{s^2 - \lambda^2}$, $\lambda^2 \geq 0$, $x = 1$. We may take

$$e_i(t) = P_1(D)\{h_1(t) * e_1(t) + e_1(t)\} + P_2(D)\{h_2(t) * e_1(t)\}. \tag{11}$$

Here $e_1(t)$ is *any* Laplace transformable pulse of length a, which, for all real t, has at least as many derivatives as the larger of the degrees of P_1 and P_2. The functions $h_1(t)$ and $h_2(t)$ are defined as

$$h_1(t) = -\lambda(t^2 - 2t)^{-1/2} I_1[\lambda(t^2 - 2t)^{1/2}],$$
$$h_2(t) = I_o[\lambda(t^2 - 2t)^{1/2}],$$

where I_0 and I_1 are the modified Bessel functions, while $*$ denotes convolution and $D = d/dt$.

Using the transform pairs[11]

$$\mathfrak{L}[h_1(t)] = e^{q-s} - 1,$$

$$\mathfrak{L}[h_2(t)] = \frac{e^{q-s}}{s},$$

one easily calculates from (11) and (9) that

$$E_o(s) = F(s)E_i(s) = P_1(s)e^{-s}E_1(s),$$

where $E_1(s) = \mathfrak{L}[e_1(t)]$; and hence

$$e_o(t) = P_1(D)e_1(t - 1).$$

Thus $e_o(t)$ is a pulse of length $1 + a$ which is zero for $0 \leq t \leq 1$.

Note that for $\lambda = 0$, (11) reduces to

$$e_i(t) = P_1(D)e_1(t) + P_2(D)\left[\int_0^t e_1(\tau)d\tau\right],$$

so that by further restricting the pulse $e_1(t)$ to have $\int_0^a e_1(\tau)d\tau = 0$, the input $e_i(t)$ is also a pulse.

2) $\alpha = LC = 0$; $F(s)$ given by (9) with $q = \sqrt{s}$, $x = 1$. We may take

$$e_i(t) = P_1(D)\left[h_3(t) + \frac{1}{\sqrt{\pi}} t^{-1/2} * \frac{dh_4(t)}{dt}\right] + P_2(D)\left[h_4(t) + \frac{1}{\sqrt{\pi}} t^{-1/2} * h_3(t)\right], \tag{12}$$

[11] A. Erdélyi, *et al.*, "Tables of Integral Transforms," McGraw-Hill Book Co., Inc., New York, N. Y., vol. 1, p. 250; 1954.

where

$$h_3(t) = \sum_{n=0}^{\infty} \frac{e_1^{(n)}(t)}{(2n)!}, \quad h_4(t) = \sum_{n=0}^{\infty} \frac{e_1^{(n)}(t)}{(2n+1)!}, \tag{13}$$

and $e_1(t)$ is *any* Laplace transformable pulse of length a, which is infinitely differentiable for all real t, and for which the infinite series implicit in (12) converge and may be Laplace transformed termwise in order to get $E_i(s)$. Here superscripts denote time derivatives, while the remainder of the notation has its previous meaning.

In Appendix II we will show that the pulse of length a defined as

$$g(t) = e^{-(1/t+1/(a-t))} \quad (0 < t < a),$$
$$g(t) = 0, \quad \text{elsewhere},$$

is an admissible function for $e_1(t)$; and more generally we may take $e_1(t) = g(t)h(t)$ where $h(t)$ is any function analytic in a sufficiently large region containing the segment $0 \leq t \leq a$.

By straightforward Laplace transform calculus, we find from (9) and (12) that

$$E_o(s) = P_1(s)E_1(s),$$

which yields

$$e_o(t) = P_1(D)e_1(t),$$

a pulse of length a.

B. Finite Line

1) $\alpha = LC \neq 0$; $F(s)$ given by (10) with $q = \sqrt{s^2 - \lambda^2}$, $\lambda^2 \geq 0$, $l = 1$. Take

$$e_i(t) = \frac{P_4(D)}{2}\left[\tilde{h}_1(t) * e_1(t) + e_1(t) + e_1(t-2)\right] + \frac{P_5(D)}{2}\left[\tilde{h}_2(t) * e_1(t)\right]. \tag{14}$$

Here, $e_1(t)$ is *any* Laplace transformable pulse of length a which, for all real t, has at least as many derivatives as the larger of the degrees of P_4 and P_5; while $\tilde{h}_1(t)$ and $\tilde{h}_2(t)$ are pulses defined in terms of the functions $h_i(t)$ $(i = 1, 2)$ of (11) as follows:

$$\tilde{h}_i(t) = h_i(t), \quad 0 \leq t \leq 2 \quad (i = 1, 2)$$
$$\tilde{h}_i(t) = 0, \quad \text{otherwise}.$$

Evidently $e_1(t)$ as given by (14) is a pulse of length $2+a$. One readily calculates the transform pairs

$$\mathfrak{L}[\tilde{h}_1(t)] = (e^{q-s} - 1) + e^{-2s}(e^{-(q-s)} - 1),$$

$$\mathfrak{L}[\tilde{h}_2(t)] = \frac{1}{q}\left[e^{q-s} - e^{-q-s}\right],$$

from which follows

$$E_o(s) = P_3(s)e^{-s}E_1(s)$$

and, finally,

$$e_o(t) = P_3(D)e_1(t-1).$$

Thus $e_o(t)$ is a pulse of length $1+a$ which is identically zero for $0 \leq t \leq 1$.

2) $\alpha = LC = 0$; $F(s)$ given by (10) with $q = \sqrt{s}$, $l = 1$. Take

$$e_i(t) = P_4(D)h_3(t) + P_5(D)h_4(t). \tag{15}$$

where $h_3(t)$ and $h_4(t)$ are pulses of length a defined by (13) in A-1. The discussion regarding $e_1(t)$ in that case applies here as well. Evidently $e_i(t)$ is a pulse of length a. By direct calculation one finds that

$$E_o(s) = P_3(s)E_1(s),$$

and so the output,

$$e_o(t) = P_3(D)e_1(t),$$

is a pulse of the same length a as the input $e_i(t)$.

VI. Example

Consider the network of Fig. 2(a), for which the transfer function is

$$F(s) = \frac{\alpha^2 + \beta^2}{(s+\alpha)^2 + \beta^2}, \quad \alpha = \frac{R}{2L}, \quad \beta^2 = \frac{1}{LC} - \left(\frac{R}{2L}\right)^2$$

We will assume that $\beta^2 > 0$.

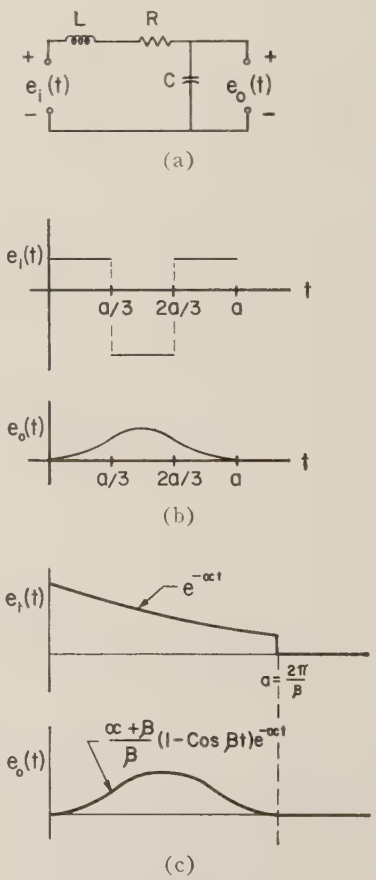


Fig. 2.

Suppose that an input pulse of arbitrary length a is desired. The method of Section IV-A, in which one works in the transform domain, will be illustrated first. Then using (4), we have

$$E_i(s)=\frac{(1-e^{-as/3})(1-e^{-a(s+\alpha-j\beta)/3})(1-e^{-a(s+\alpha+j\beta)/3})}{s}, \quad (16)$$

since $F(s)$ has the poles $-\alpha\pm j\beta$, and $n=2$, $\epsilon=a/3$. Multiplying out the factors in (16) and inverting gives

$$e_i(t) = u(t) - c_1u\left(t-\frac{a}{3}\right) + c_2u\left(t-\frac{2a}{3}\right) - c_3u(t-a),$$

where

$$c_1 = 1 + 2e^{-a\alpha/3}\cos\frac{a\beta}{3}, \qquad c_2 = e^{-2a\alpha/3} + 2e^{-a\alpha/3}\cos\frac{a\beta}{3},$$

$$c_3 = e^{-2a\alpha/3},$$

and $u(t)$ is the unit step function.

Thus the input consists of three rectangular pulses whose amplitudes are respectively 1, $1-c_1$, $1-c_1+c_2$, and which are defined in the intervals $(0, a/3)$, $(a/3, 2a/3)$, $(2a/3, a)$, respectively [*cf.*, Fig. 2(b)].

The output pulse is found to be

$$e_o(t) = h(t) - c_1h(t-a/3) + c_2h(t-2a/3) - c_3h(t-a),$$

where

$$h(t) = u(t) - e^{-\alpha t}\left(\cos\beta t + \frac{\alpha\sin\beta t}{\beta}\right), \qquad t\geq 0$$
$$= 0 \qquad t<0.$$

Since $s^2E_o(s)=s^2E_i(s)F(s)$ is a finite Laplace transform, Theorem 2 of Section II implies that the pulse $e_o(t)$ has an ordinary first derivative for all t. Thus, the slope of $e_o(t)$ is zero at both ends of the pulse interval. Fig. 2(b) pictures $e_o(t)$ when a is small compared to $1/\alpha$ and $1/\beta$.

As indicated in Section IV-A, a choice of $E_i(s)$ may be made in many different ways and this gives us the freedom to impose additional restrictions on the type of input pulse we desire. For example, suppose the pulse length a is immaterial but we desire the input to be in "one piece." A glance at (16) shows that the separate "pieces" of our first solution arose because of the various exponential terms in the numerator. Therefore, we attempt to find a suitable $E_i(s)$ by using just one exponential in the numerator. The simplest such finite Laplace transform is of the form

$$E_i(s) = \frac{1-e^{-a(s+\delta)}}{s+\delta},$$

where $a>0$ and δ are to be determined so as to make the output a pulse.

The requirement that $E_i(s)$ must be zero at the poles of $F(s)$ leads to the condition

$$a(-\alpha+j\beta+\delta) = 2n\pi j, \qquad n \text{ an integer.}$$

The choice $\delta=\alpha$, $n=1$, $a=2\pi/\beta$ can be used here. The resulting input and output pulses of length $2\pi/\beta$ are shown in Fig. 2(c).

Next, we consider the method of Section IV-B where the solution is represented directly in the time domain. Since $N(s)=\alpha^2+\beta^2$ and $D(s)=\alpha^2+\beta^2+2\alpha s+s^2$ in our example, (5) and (6) become, respectively,

$$e_i(t) = (\alpha^2+\beta^2)e_1(t) + 2\alpha\frac{de_1(t)}{dt} + \frac{d^2e_1(t)}{dt^2}$$

and

$$e_o(t) = (\alpha^2+\beta^2)e_1(t).$$

Here $e_1(t)$ may be any pulse of length a having at least a generalized second derivative for all t. For an input pulse without jumps, $e_1(t)$ must have an ordinary second derivative for all t. For example, a suitable function $e_1(t)$ of this latter class would be

$$e_1(t) = (1-\cos\omega t)^2, \qquad 0\leq t\leq a$$
$$= 0, \qquad \text{otherwise,}$$

where $a=2\pi/\omega$. This choice of $e_1(t)$ leads to the input pulse

$$e_1(t) = \frac{3}{2}(\alpha^2+\beta^2) + 2(\omega^2-\alpha^2-\beta^2)\cos\omega t + 2\alpha\omega\sin\omega t + \tfrac{1}{2}(\alpha^2+\beta^2-4\omega^2)\cos 2\omega t - \alpha\omega\sin 2\omega t, \qquad (0\leq t\leq a)$$
$$= 0, \quad \text{otherwise.}$$

This sort of pulse shape has the advantage that it can be produced by gating a continuous wave rather than by generating the individual pulse.

Appendix I

The Fundamental Equations of Section IV-B

We must show that the relation

$$F_o(s) = \frac{N(s)}{D(s)}E_i(s) \quad (17)$$

with

$$N(s) = \sum_{i=0}^{m} k_is^i, \quad D(s) = \sum_{i=0}^{n} h_is^i, \quad h_n = 1, \; m\leq n, \; n\geq 0,$$

$N(s)$ and $D(s)$ relatively prime, plus the assumptions that $E_i(s)$ and $E_o(s)$ satisfy the conditions in Theorem 1 of Section II, imply that

$$e_i(t) = h_0e_1(t) + h_1e_1'(t) + h_2e_1''(t) + \cdots + h_ne_1^{[n]}(t), \quad (18)$$

$$e_o(t) = k_0e_1(t) + k_1e_1'(t) + k_2e_1''(t) + \cdots + k_me_1^{(m)}(t). \quad (19)$$

Here $e_1(t)$ is a pulse having a Laplace transformable generalized nth derivative [denoted by $e_1^{[n]}(t)$] in the pulse interval $(0, a)$, and satisfying the conditions

$e_1(0^+) = e_1'(0^+) = \cdots = e_1^{(n-1)}(0^+) = 0 = e_1(a^-) = e_1'(a^-) = \cdots = e_1^{(n-1)}(a^-)$ at the ends of this interval.[4,5]

In (17), since $E_0(s)$ and $E_i(s)$ are entire, we must have

$$E_i(s) = D(s)E_1(s), \tag{20}$$

where $E_1(s)$ is an entire function.

We will show that $E_1(s)$ satisfies the conditions of Theorem 2 of Section II. We already have condition a of that theorem. There remains the proof that $s^nE_1(s)$ is a finite Laplace transform.

From (20), we have

$$s^nE_1(s) = \frac{s^n}{D(s)} \cdot E_i(s) = E_i(s) + \frac{N_1(s)}{D(s)} \cdot E_i(s), \tag{21}$$

where $N_1 = s^n - D(s)$ is of lower degree than $D(s)$. Now $N_1(s)E_i(s)/D(s)$ is an entire function and is a Laplace transform by the convolution theorem. Also, since $N_1(s)/D(s) \to 0$ as $s \to \infty$, the inequalities b and c of Theorem 1, Section II, hold for $N_1(s)E_i(s)/D(s)$ and with the same constant a as for $E_i(s)$. Thus by Theorem 1 of Section II, $N_1(s)E_i(s)/D(s)$ is a finite Laplace transform. Then, by (21), $s^nE_1(s)$ is a finite Laplace transform of length a.

We may therefore apply Theorem 2 of Section II to $E_1(s)$ and infer that $e_1(t)$ is a pulse having the differentiability properties stated above. As a consequence of this, $\mathfrak{L}[e_1^{(k)}(t)] = s^kE_1(s)$, $(k = 0, 1, \cdots, n)$. Therefore, inverting (20) termwise yields (18). Eq. (19) is obtained by eliminating $E_i(s)$ between (17) and (20) and inverting the resulting equation for $E_o(s)$.

The converse result, that pulses $e_i(t)$ and $e_o(t)$ defined by (18) and (19) are solutions of (17), with $e_1(t)$ as *any* pulse having the stated properties, is immediate.

Eqs. (18) and (19) can be extended in an obvious way to include inputs which may have impulses of any order.

Appendix II

The Convergence of (12) and (15)

If the indicated differentiations $P_1(D)$, $P_2(D)$, etc., in (12) and (15) are carried out, there result expressions which involve a finite number of infinite series of the two general forms:

$$S_1 = \sum_{n=0}^{\infty} \frac{e_1^{(n+k)}(t)}{(2n)!}, \qquad S_2 = \sum_{n=0}^{\infty} \frac{e_1^{(n+k)}(t)}{(2n+1)!},$$

where k may vary from series to series, but in any one series is a fixed non-negative integer.

To begin, we suppose that $e_1(t)$ is a function defined as

$$\begin{aligned} g(t) &= e^{-(1/t - 1/(a-t))}, && 0 < t < a \\ &= 0, && \text{otherwise.} \end{aligned} \tag{22}$$

We will show that, for this choice of $e_1(t)$, the series S_1 and S_2 are absolutely and uniformly convergent in the closed interval $0 \le t \le a$. This not only establishes that these series have meaning, but also justifies calculating the Laplace transform of S_1 and S_2 by transforming the series termwise.

The proof will depend upon the establishment of the following inequality for $g^{(n)}(t)$:

$$|g^{(n)}(t)| \le (n+1)!n^n\beta^n, \quad (n = 0, 1, 2, \cdots,), 0 \le t \le a, \tag{23}$$

where β is a constant such that $0 < \beta < 1$. Assuming for the moment that (23) holds, then the stated result can be obtained readily. It suffices to consider S_1. Then, using simply the rough inequality $2n! \ge n!n^n$, we have

$$\left|\frac{g^{(n+k)}(t)}{(2n)!}\right| \le \frac{(n+k+1)!(n+k)^{n+k}\beta^{n+k}}{n!n^n}$$

$$= (n+k+1)(n+k)\cdots(n+1)(n+k)^k(1+k/n)^n\beta^{n+k}.$$

Since

$$\left(1 + \frac{k}{n}\right)^n \to e^k \text{ as } n \to \infty,$$

we have

$$\left|\frac{g^{(n+k)}(t)}{(2n)!}\right| \le CP(n)\beta^{n+k},$$

where C is a bound for

$$\left(1 + \frac{k}{n}\right)^n \text{ and } P(n) = (n+k+1)\cdots(n+1)(n+k)^k$$

is a polynomial in n of fixed degree. Thus S_1 is majorized for all $0 \le t \le a$ by the convergent series $C\beta^k\sum P(n)\beta^n$, and our result follows.

The remainder of this section therefore will be devoted to the proof of (23). We consider first the simpler function $f(t)$ defined as

$$\begin{aligned} f(t) &= e^{-1/t}, && t > 0, \\ &= 0, && \text{otherwise.} \end{aligned}$$

Then $f(t)$ has derivatives of all orders and $f^{(n)}(0) = 0$, $(n = 0, 1, \cdots)$. The function $e^{-1/t}$ considered as a function of a complex variable t is analytic everywhere except at $t = 0$ where it has an essential singularity.

Let z be any positive number. Then by the Cauchy integral formula:

$$f^{(n)}(z) = \frac{n!}{2\pi i}\int_C \frac{e^{-1/t}dt}{(t-z)^{n+1}},$$

where for C we take the circle $C: t = z + re^{i\theta}$, $0 \le \theta \le 2\pi$, with $0 < r < z$ (see Fig. 3).

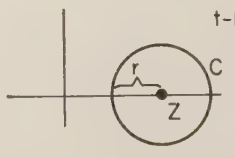


Fig. 3.

By a standard inequality,

$$|f^{(n)}(z)| \leq \frac{n!}{2\pi}\cdot\max\left|\frac{e^{-1/t}}{(t-z)^{n+1}}\right| \text{ on } C\cdot 2\pi r,$$

$$\leq \frac{n!}{r^n}\cdot\max|e^{-1/t}| \text{ on } C.$$

But on C,

$$|e^{-1/t}| = e^{-(z+r\cos\theta)/(z^2+r^2+2rz\cos\theta)}$$

$$= e^{-1/2z}\cdot e^{-A/(z^2+r^2+2rz\cos\theta)},$$

where $A=(z^2-r^2)/2z>0$. Therefore,

$$\max|e^{-1/t}| \text{ on } C = e^{-1/2z}\cdot e^{-A/(z+r)^2} = e^{-1/(z+r)}.$$

Thus,

$$|f^{(n)}(z)| \leq \frac{n!}{r^n}e^{-1/(z+r)}. \tag{24}$$

Up to this point, r has been independent of z, subject only to the condition that $0<r<z$. We now take $r=\alpha z$ where α, a constant subject to the inequality $0<\alpha<1$, is to be determined later. Then (24) becomes

$$|f^{(n)}(z)| \leq \frac{n!}{\alpha^n z^n}e^{-1/(1+\alpha)z}, \qquad z>0. \tag{25}$$

This inequality holds also for $z=0$ if we interpret the right member as $\lim_{z\to 0^+}$, since both members are then zero.

We now determine a bound for the right member of (25) which is independent of z. Consider the function

$$h(z) = \frac{1}{z^n}\cdot e^{-1/(1+\alpha)z}$$

for $z\geq 0$, $n\geq 1$. Then

$$\frac{dh(z)}{dz} = \left[\frac{1}{(1+\alpha)z} - n\right]\frac{e^{-1/(1+\alpha)z}}{z^{n+1}}. \tag{26}$$

It follows from (26) and from the fact that

$$h(0) = h(\infty) = 0,$$

that $h(z)$ attains its maximum at $z=1/(1+\alpha)n$, so that

$$\max h(z) = (1+\alpha)^n n^n e^{-n}, \qquad z\geq 0.$$

Thus (25) becomes

$$|f^{(n)}(z)| \leq n!n^n\beta^n, \qquad \beta = \frac{1+\alpha}{\alpha e}, \tag{27}$$

for $z\geq 0$, $n\geq 1$. By inspection, $|f(z)|\leq 1$ for all z, and if 1 is the value assigned to the right member of (27) when $n=0$, (27) holds also for $n=0$. Trivially, (27) holds for $z<0$.

Since $(1+\alpha)/\alpha e<1$ if $\alpha>1/(e-1)$ and since this last inequality can be satisfied with an α such that $0<\alpha<1$ (*e.g.*, $\alpha=\frac{3}{4}$), it follows that we may suppose that $0<\beta<1$. The inequality (27), except for the presence of $n!$ instead of $(n+1)!$ is (23) for the function $f(t)$.

Next consider $f_1(t)$ defined by

$$f_1(t) = e^{-1/(a-t)}, \quad t<a,$$

$$= 0, \quad \text{otherwise.}$$

Then since $f_1(t)=f(a-t)$ and $|f_1^{(n)}(t)| = |f^{(n)}(a-t)|$, $f_1^{(n)}(z)$ is also subject to the inequality (27) for all z.

Finally, noting that $g(t)=f(t)f_1(t)$, we apply Leibniz's rule for the nth derivative of a product to $g(t)$ and find

$$g^{(n)}(t) = \sum_{i=0}^{n}\binom{n}{i}f^{(i)}(t)f_1^{(n-i)}(t).$$

Then in view of (27), which holds for both $f(t)$ and $f_1(t)$, we get

$$|g^{(n)}(t)| \leq \sum_{i=0}^{n}\binom{n}{i}|f^{(i)}(t)|\,|f_1^{(n-i)}(t)|$$

$$\leq \sum_{i=0}^{n}\binom{n}{i}i!i^i\beta^i\cdot(n-i)!(n-i)^{n-i}\beta^{n-i}.$$

As

$$\binom{n}{i} = n!/(n-i)!i!,$$

and $(n-i)^{n-i}i^i\leq n^n$, it follows that

$$|g^{(n)}(t)| \leq (n+1)\cdot n!n^n\beta^n.$$

This is (23).

The convergence of the series S_1 and S_2 may also be proved when, more generally, $e_1(t)=g(t)h(t)$ where $h(t)$ is any function analytic in a region which contains the rectangle R:

$$-\beta^{-1}\leq \mathrm{Re}\,(t)\leq a+\beta^{-1}, \quad -\beta^{-1}\leq \mathrm{Im}\,(t)\leq\beta^{-1}.$$

Here β is the constant in (23) and a is the pulse length of $g(t)$.

For, if t is any real number in the interval $0\leq t\leq a$ then, as is well known, we have $|h^{(n)}(t)|\leq n!M_t/r^n$, where M_t is the maximum of $|h(t)|$ on a circle of radius r with center at t. The circular disk of radius r centered at t must be interior to the region of analyticity of $h(t)$. Since this region contains R, we can choose $r=\beta^{-1}$. Also $M_t\leq M$ where M is the maximum of $|h(t)|$ on the boundary of R. There results the inequality

$$|h^{(n)}(t)| \leq Mn!\beta^n. \tag{28}$$

If we now apply the Leibniz formula to get $d^n[g(t)h(t)]/dt^n$ and employ (23) and (28), we find

$$\left|\frac{d^n}{dt^n}[g(t)h(t)]\right| \leq M\sum_{i=0}^{n}\binom{n}{i}(i+1)!i^i\beta^i(n-i)!\beta^{n-i},$$

$$\leq Mn!n^n\beta^n\sum_{i=0}^{n}(i+1) = \frac{M}{2}(n+2)!n^n\beta^n.$$

Since this inequality is essentially like (23) with the right member there multiplied by $(n+2)$, the argument given at the beginning of this section is unaffected when $g(t)$ is replaced by $g(t)h(t)$.

Correspondence

Generation of Nanosecond Carrier Pulses at *X*-Band with Tunnel Diodes*

A gallium antimonide[1] point contact[2] tunnel diode has been used to obtain nanosecond carrier pulses at a 10-Mc rate in *X*-band waveguide. The RF pulse of Fig. 1 was generated directly from the switching of this tunnel diode with the 10-Mc pulse. Fig. 1(b) shows a single pulse of Fig. 1(a) in an expanded time scale.

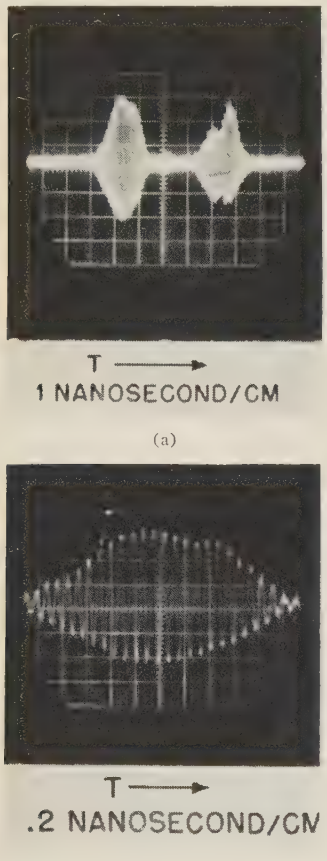


Fig. 1—(a) RF pulses from GaSb tunnel diode. (b) RF cycles in pulse.

Since the waveguide acts as a high-pass or differentiating circuit, one RF pulse is generated as the rising edge of the driving pulse causes the diode to switch to the high-current state; a second pulse is generated as the falling portion of the driving pulse returns the diode to the zero-current condition. The separation between pulses depends on the time that the driving pulse amplitude exceeds the valley voltage.

The pulses were observed on the electronic band-pass stroboscope described by A. F. Dietrich in his letter.[3] Examination of Fig. 1(b) shows there are $2\frac{1}{4}$ RF cycles per cm. Since the horizontal sensitivity is 2×10^{-10} sec/cm, the pulse has a carrier frequency of 11 Gc.

The gallium antimonide diode was mounted without encapsulation directly across a 0.015 inch×0.9 inch *X*-band waveguide (Fig. 2). The diode was formed[1] after assembly in the guide. The I-V characteristics of this diode are shown in Fig. 3. The 10-Mc pulse was coupled to the coaxial line leading to the diode by a broad-band ferrite transformer. For this pulsed operation no dc bias was used.

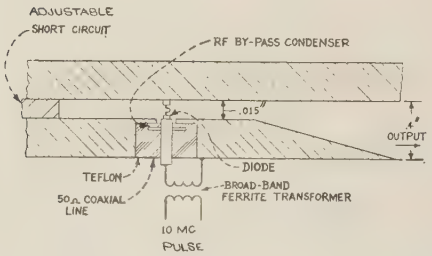


Fig. 2—Tunnel diode pulse circuit.

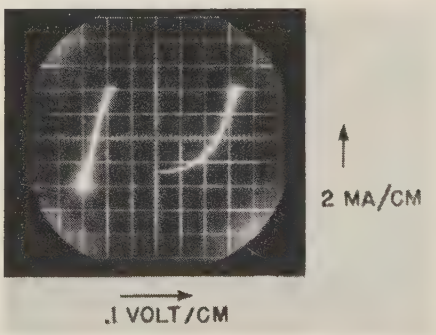


Fig. 3—Gallium antimonide tunnel diode I-V characteristic.

The power output, conversion efficiency and the results of operation of higher carrier frequencies will be reported in the near future.

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* Received by the IRE, April 12, 1961.

[1] C. A. Burrus, "Gallium antimonide Esaki diodes for high frequency applications," to be published.

[2] C. A. Burrus, "Esaki diodes for high frequency applications," to be published in *J. Appl. Phys.*

[3] A. F. Dietrich, "8 and 11 Gc nanosecond pulses produced by harmonic generation," accepted for publication in Proc. IRE.

Circuit Control of Tunnel Diode Negative-Resistance Characteristics*

The February, 1961, Paris Conference on Semiconductor Devices included a discussion by S. Amer and W. Fulop concerning a distributed junction tunnel diode in which lateral current flow in one degenerate region, provided with two ohmic contacts, controlled the tunnel negative-resistance curve. This parallels some studies at the Carnegie Institute of Technology in which the emphasis has been on similarly controlling several small area junctions alloyed to the same wafer, or a number of separate lumped circuit elements. Long rectangular junctions involve inconveniently large peak currents and capacitances, and appear to us to possess no compensating advantages.

A typical circuit studied is shown in Fig. 1 where I_d and V_d represent the output quantities, while I_c and V_c are the control parameters. Current I_c in the resistances R_{c1} and R_{c2} biases the individual tunnel junctions, and results in output characteristics with controlled variation of negative resistance as shown in Fig. 2. The resistances R_{c1} and R_{c2} are usually chosen about equal to the negative resistance of a single junction: for example, 300 ohms for the germanium $\frac{1}{3}$-ma peak current units of Fig. 2. The cur-

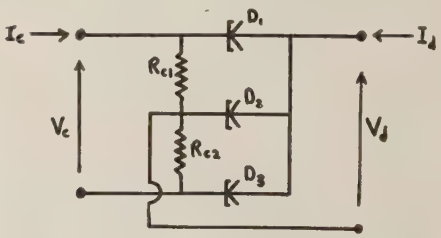


Fig. 1—Three-diode circuit giving control of the tunnel characteristics I_d and V_d.

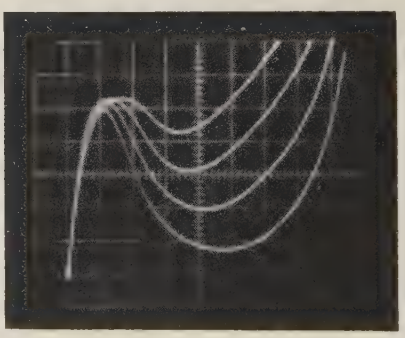


Fig. 2—Tunnel diode current I_d vs voltage V_d for control currents I_c of 0.4, 0.65, 0.9, and 1.15 ma with the circuit of Fig. 1. Vertical and horizontal scales are 0.2 ma and 50 mv per large division respectively.

* Received by the IRE, April 14, 1961.

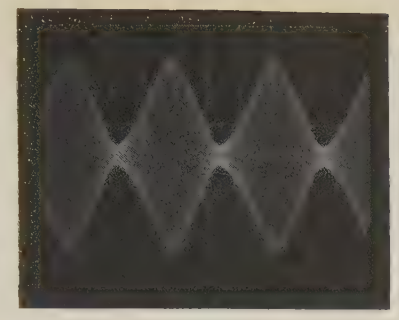


Fig. 3—Modulation of a 100-kc oscillation produced by a sinusoidal control signal superimposed on I_c in Fig. 1. The vertical and horizontal scales are 50 mv and 5 msec per large division, respectively.

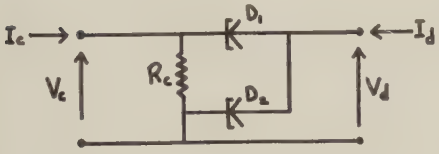


Fig. 4—Two-diode control circuit with common input-output line.

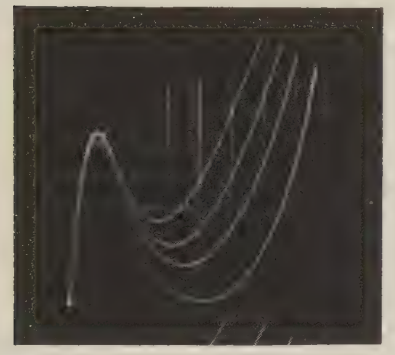


Fig. 5—Tunnel diode current I_d vs voltage V_d for control current I_c values of 0.40, 0.55, 0.70, and 0.85 ma in Fig. 4. Vertical and horizontal scales are 0.1 ma and 50 mv per large division, respectively.

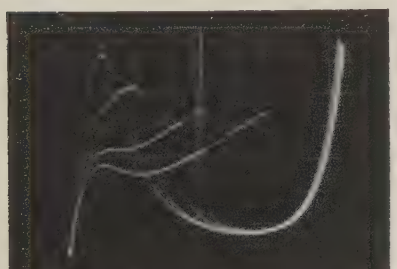


Fig. 6—Control characteristics I_d vs V_d obtained with the circuit of Fig. 4. R_c values are 0, 125, 300, and 550 ohms with $I_c=0$. Vertical and horizontal calibrations are 0.1 ma and 50 mv per large division, respectively.

rent required for full control tends to be about the same magnitude as the peak tunnel current that is controlled. If higher sensitivity is required, the possibility exists for field-effect transistor or bipolar transistor control of I_c.

The control of negative resistance and peak-to-valley ratio that has been demonstrated makes possible many useful circuit functions including variable gain amplification, variable swing relaxation oscillators, and variable threshold switching gates. Fig. 3 illustrates amplitude modulation of a 100-kc oscillation obtained with an LC tank circuit and dc bias in series with the output terminals of Fig. 1, and 60-cps modulation of I_c.

If a common input-output line is required, the even simpler two diode circuit of Fig. 4 is available. Here, there is a little more difficulty in selecting diodes to give the characteristic change required. Fig. 5 shows the curves obtained for matched 0.25 ma peak-current germanium-tunnel diodes with R_c about 200 ohms, and I_c as the parameter. Curves of unusual shape may be produced by a deliberate mismatching of the diodes with respect to characteristics or material. The magnitude of R_c is also a control factor as shown in Fig. 6, where the diodes are mismatched by 2:1, the control current is zero, and R_c is changed in steps to several times the normal value.

Partial support of these studies by the Westinghouse Semiconductor Division, Youngwood, Pa., is gratefully acknowledged.

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Sensitivity of the Degenerate Parametric Amplifier*

The noise temperature of a degenerate parametric amplifier (double channel) is approximately equal to half that for a nondegenerate amplifier[1] using the same varactor at the same signal frequency and pumped at its optimum pump frequency. The optimum pump frequency (for minimum noise) in a nondegenerate amplifier is approximately equal to γf_{co}, where γ is a capacitance modulation coefficient[1] and f_{co} is the cutoff frequency for the mean operating capacity. For good varactors at the present day, γf_{co} is well above 20 kMc. For radiometric applications, there is thus an advantage in using a degenerate amplifier rather than a nondegenerate one requiring a high pump frequency.

A degenerate parametric amplifier has its input circuit tuned to half the pump frequency f_p, so that the signal and "idler" frequency channels coincide. For a signal at frequency f, the amplified output consists of a component reflected from the input at frequency f, and a component converted to (f_p-f). For high gain these components are equal in amplitude and have in general equal band-pass characteristics symmetric with respect to the frequency $\frac{1}{2}f_p$. If the input is noise, the result is that the noise in the frequency band below $\frac{1}{2}f_p$ is fully correlated with the noise in the frequency band above $\frac{1}{2}f_p$. This correlation can be shown to lead to an increase in the post-detector fluctuations, and so to an increase in the minimum detectable signal.

The reflected narrow-band noise signal can be represented by

$$X_R(t) = X_c(t)\cos\tfrac{1}{2}\omega_p t + X_s(t)\sin\tfrac{1}{2}\omega_p t, \quad (1)$$

where $X_c(t)$ and $X_s(t)$ are independent, slowly fluctuating quantities which have equal rms values and equal normalized autocorrelation functions, $c(s)$. For a pump waveform $\cos(\omega_p t+\phi_p)$, a reflected Fourier component $A_n\cos(n\omega t+\phi_n)$ is accompanied at high gain by a converted component $A_n\cos(\omega_p t-n\omega t-\phi_n+\phi_p)$. Then the degenerate noise output, which is the sum of the reflected and converted components, can be represented by

$$X_D(t) = 2X_d(t)\cos(\tfrac{1}{2}\omega_p t + \tfrac{1}{2}\phi_p), \quad (2)$$

where

$$X_d(t) = X_c(t)\cos\tfrac{1}{2}\phi_p - X_s(t)\sin\tfrac{1}{2}\phi_p$$

and so has the same autocorrelation function as $X_c(t)$ and $X_s(t)$. The post-detector noise fluctuations can be calculated most easily in the case of a quadratic detector followed by an RC filter of time constant τ. If the relative rms fluctuation in the filtered output is $\sqrt{\alpha}$,[2] then when the degenerate noise output (2) is applied to the detector, we have

$$\alpha \doteq 2/\tau\int_0^\infty c^2(s)ds,$$

which is just twice as large as in the case when only the nondegenerate noise signal (1) is applied to the detector.

The increase in the post-detector fluctuations in a degenerate amplifier by a factor $\sqrt{2}$ has been verified experimentally. Since α is inversely proportional to the amplifier bandwidth, the effective bandwidth for noise may be thought of as halved for the degenerate noise output.

If we therefore compare a degenerate amplifier with an optimum nondegenerate amplifier using the same varactor, we find that the capability of detecting a weak noise signal is only $\sqrt{2}$ better in the degenerate case if the signal bandwidths are equal. Another case is that where a degenerate amplifier is followed by a receiver with a pass band narrower than that of the amplifier, which is of practical concern for multiple-tuned[3,4] amplifiers. When the receiver is tuned completely to one side of $\frac{1}{2}f_p$

* Received by the IRE, April 7, 1961. This work has been carried out under the auspices of the Netherlands Foundation for Radio Astronomy [supported by the Netherlands Organisation for Pure Research (ZWO)] and the Radiophysics Laboratory of CSIRO, Australia.

[1] K. L. Kotzebue, "Optimum noise performance of parametric amplifiers," Proc. IRE, vol. 48, pp. 1324–1325; July, 1960.

[2] A. van der Ziel, "Noise," Prentice-Hall, Inc., New York, N. Y., ch. 13; 1954.

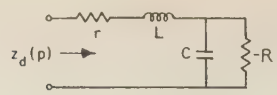
[3] B. T. Vincent, "A high-performance X-band parametric amplifier," Proc. IRE, vol. 49, pp. 511–512; February, 1961.

[4] A. G. Little, "A wide band single diode parametric amplifier using filter techniques," Proc. IRE, in press.

("quasi-degenerate"), the sensitivity for wide-band noise will be $\sqrt{2}$ better than when the receiver is centered on $\frac{1}{2}f_p$, provided that the antenna and circulator can pass both the signal and "idler" frequencies. These comparisons hold whatever the value of the antenna temperature.

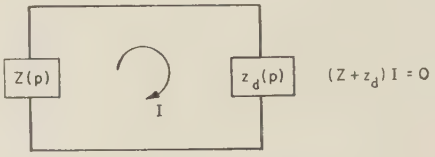
The increase in the noise fluctuations is a particular case of the limitations imposed by the loss of spectral information when a degenerate amplifier is used.

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$0 \leq r$ = junction spreading resistance, Ω
$0 \leq L$ = series inductance, h
$0 \leq C$ = junction capacitance, f
$0 \leq R$ = magnitude of negative resistance shunting C, Ω

Fig. 1—Equivalent circuit of a tunnel diode operating in the linear mode.



$Z(p)$ = passive impedance
$z_d(p)$ = 2-terminal active device

Fig. 2—Schematic illustrating the meaning of potential stability.

Stability Criteria for Tunnel Diodes*

The tunnel diode provides network designers with a simple and practical two-terminal negative resistance device whose equivalent circuit, when operating in the linear mode, is that shown in Fig. 1. This representation appears to be valid up to at least 10 kMc. In several recent papers[1-4] devoted to the analysis of amplifiers incorporating tunnel diodes in a passive environment, it has been shown that large gains, wide bandwidths and relatively low noise figures are compatible and achievable with practical configurations.

In order that a two-terminal element, $z_d(p)$, be usable as a basic component in the synthesis of an amplifier, it must be capable of operating in a stable manner under at least one passive termination (Fig. 2). This leads to the following definition.

Definition: A two-terminal device, $z_d(p)$, is *potentially stable* if there exists at least one finite positive real function $Z(p)$ such that the equation

$$Z(p) + z_d(p) = 0 \tag{1}$$

has no solutions in the closed right-half p-plane, Re $p \geq 0$. $Z(p)$ is said to stabilize $z_d(p)$. In the contrary case, $z_d(p)$ is called *totally unstable.*

Thus, if $Z(p)$ stabilizes $z_d(p)$, the current I circulating in the closed loop of Fig. 2 is zero for all p in Re $p \geq 0$. On the other hand, a totally unstable $z_d(p)$ will always oscillate (or burn out) when placed in a passive environment and therefore is useless as far as linear controlled amplification is concerned.

Here we collate and discuss various stability criteria for the tunnel diode depicted in Fig. 1. The results are stated in the form of theorems and all proofs are omitted.

Theorem 1: The two conditions

$$\frac{r}{R} < 1 \tag{2}$$

and

$$\frac{L}{R^2C} < 3 \tag{3}$$

are both necessary for the potential stability of a tunnel diode.

The first inequality (2) is automatically satisfied for all present-day commercially available diodes ($r/R \approx 0.01$), but the second is not and must be checked. For example, the GE ZJ61-22 diode which is ordinarily used in high-speed switching applications has a ratio $L/R^2C = 3.75$.

Theorem 2:[1] For dissipationless tunnel diodes ($r=0$), the condition

$$\frac{L}{R^2C} < 3 \tag{4}$$

is necessary and sufficient for potential stability.

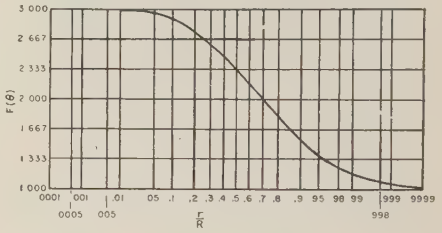
The authors previously gave a rigorous derivation of (4) and proved its sufficiency by exhibiting a stable reflection amplifier design.[1] Now, of course, r is never zero, so that Theorem 2 does not quite cover all practical situations. The next theorem is much sharper; but before stating it, it is necessary to introduce some abbreviations:

$$f_r = \frac{1}{2\pi RC}\sqrt{\frac{R}{r} - 1} \tag{5}$$

$$\theta = \frac{1}{2\pi f_r RC} = \sqrt{\frac{r/R}{1 - r/R}}, \tag{6}$$

$$F(\theta) = \frac{\theta^3}{1+\theta^2} \cdot \frac{1}{\theta - \arctan\theta}, \tag{7}$$

where f_r is the familiar resistive cutoff frequency. The function $F(\theta)$ plays a leading role in Theorem 3 and is plotted in Fig. 3 as a function of the parameter r/R. Note that its maximum value, 3, is attained for $r=0$ and its minimum value, 1, for $r=R$. The transition between the two extremes is monotonic.



r = junction resistance, Ω
L = series inductance, h
C = junction capacitance, f
R = magnitude of negative resistance, Ω
$L < F(\theta)$.
R^2C

Fig. 3—Plot of $F(\theta)$ vs r/R.

Theorem 3:[5] For a tunnel diode, the two conditions

$$\frac{r}{R} < 1 \tag{8}$$

and

$$\frac{L}{R^2C} < F(\theta) \tag{9}$$

are both necessary for potential stability.

The inequality (8) is the same as (2) and contributes nothing new. But since $F(\theta) \leq 3$, Theorem 3 improves Theorem 1. Work now in progress seems to indicate that (8) and (9) are actually necessary and sufficient. This conjecture is true when $r=0$, for then $\theta=0$, $F(\theta)=3$ and (9) collapses into $L/R^2C<3$, which according to Theorem 2 is indeed necessary and sufficient for potential stability. For additional discussion, the reader should consult the authors' report.[5] To date, (8) and (9) appear to be the most complete set of criteria available for checking stability of a general tunnel diode.

To see how Theorem 3 works, consider the Hoffman HT-10 tunnel diode. The corresponding parameters (typical values) are

$r = 1\ \Omega$
$L = 20\ \text{m}\mu h$ (at 1/4-inch lead length)
$C = 10\ \mu\mu f$
$R = 39\ \Omega (\pm 20$ per cent).

By direct calculation, $r/R = 0.025$, $L/R^2C = 1.32$ and $F(\theta) = 2.97$. Thus, $L/R^2C < F(\theta)$ and the diode may be potentially stable. Observe that Hines' test (Theorem 4) is not applicable.

The next and final theorem is probably the earliest known sufficient condition for the potential stability of a tunnel diode.

* Received by the IRE, March 31, 1961. The work reported in this paper was sponsored by the Rome Air Dev. Ctr. Air Res. and Dev. Command under Contract No. AF-30(602)-2213.

[1] L. I. Smilen and D. C. Youla, "Exact theory and synthesis of a class of tunnel diode amplifiers," *Proc. NEC* vol. 16, pp. 376–404; October, 1960.

[2] D. C. Youla and L. I. Smilen, "Optimum negative resistance amplifiers," *Proc. Symp. on Active Networks and Feedback Systems*, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., vol. 10, pp. 241–318; April, 1960.

[3] H. J. Carlin and D. C. Youla, "Network synthesis with negative resistors," *Proc. Symp. on Active Networks and Feedback Systems*, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., vol. 10, pp. 27–67; April; 1960.

[4] E. W. Sard, "Gain-bandwidth performance of maximally flat negative resistance amplifiers," *Proc. Symp. on Active Networks and Feedback Systems*, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., vol. 10, pp. 319–344; April, 1960.

[5] L. I. Smilen and D. C. Youla, "On the Stability of Tunnel Diodes," Networks and Waveguide Group, Microwave Res. Inst., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., Memorandum 49, PIBMRI-889-61; in preparation.

Theorem 4:[6] The two conditions

$$r < R \tag{10}$$

and

$$\frac{L}{R^2C} < 1 \tag{11}$$

are sufficient for the potential stability of a tunnel diode. Moreover, the diode may be stabilized with a positive resistor R_s. Any value of R_s satisfying the inequalities

$$1 > \frac{r + R_s}{R} > \frac{L}{R^2C} \tag{12}$$

suffices.

Since the minimum value of $F(\theta)$ is unity, any diode satisfying (10) and (11) certainly passes the test of Theorem 3. Hence, if Theorem 3 can be proved sufficient as well as necessary, it will contain Theorem 4 as a corollary. Any new results will be reported in future letters.

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[6] M. E. Hines, "High-frequency negative-resistance circuit principles for Esaki diode applications," *Bell Sys. Tech. J.*, vol. 39, pp. 477–513; May, 1960.

On the Possibility of Drift-Tunnel Oscillations in High-Power Klystrons*

During the design and development of the Stanford University high-power klystron [1] in 1953, some 5.2-cm wavelength (5770 Mc) spurious signals were radiated from both input and output terminals with no RF drive signal applied. These spurious signals were accurately measured and they were not second harmonics of the design frequency of the klystron. Tuning the klystron cavities changed the frequency and amplitude of the spurious oscillations. It is conjectured that the oscillation frequencies are governed by 1) the dimensions of the drift tunnels, 2) the internal geometry of the terminating cavities, and 3) a negative resistance derived from long transit angles of a transversally-displaced electron beam in the drift tunnel.

Negative resistances have been generated between cathode and anode in planar [2, 3] and inverted spherical [4] diodes when the electron transit time is about $n+\frac{1}{4}$ ($n=1, 2, 3 \cdots$) RF cycles. In these diodes the direction of the RF electric field is substantially in the direction of the electron beam.

In a different type of electron tube, where the RF electric field is perpendicular to the direction of the electron beam, Fank [5] has calculated that negative resistances can be generated provided a transversally-displaced electron beam can deliver energy to a fringing longitudinal RF electric field after a transit time of $n+\frac{1}{4}$ RF cycles. For the present analysis of the Stanford klystron, Fank's parallel-plate gap can be replaced by a circular drift tunnel which supports a resonant transverse-electric $TE_{11}°$ mode and the qualitative behavior is quite similar in the two configurations. Thus, negative resistances may be generated when the transit time in the tunnel is $n+\frac{1}{4}$ cycles. This infers that drift tunnel oscillations should depend on beam voltage.

In a circular waveguide, the cutoff frequency f_c of the dominant $TE_{11}°$ mode is given by

$$f_cD = 6917\text{-Mc inches},$$

where

f_c = cutoff frequency, megacycles,
D = diameter, inches.

The normalized resonant frequency of an open-ended circular waveguide neglecting fringing fields is given by

$$\frac{f}{f_c} = \sqrt{1 + \left(\frac{mc}{2Lf_c}\right)^2} = \sqrt{1 + 0.728\left(\frac{mD}{L}\right)^2}, \tag{1}$$

where

m = integer, number of half-guide wavelengths,
c = velocity of light, 1.1802×10^{10} inches per second,
L = tunnel length, inches.

Eq. (1) is plotted in Fig. 1 for convenience.[1] In a klystron, the cavities terminating the drift tunnels will present impedances differing from that of an open circuit. Hence, the resonant frequency of the tunnel may differ from that given by (1) and cavity tuning should vary the tunnel resonant frequency.

As stated above, negative resistances may be generated when the transit time is approximately equal to $n+\frac{1}{4}$ RF cycles. Thus a frequency f which will meet this criterion under relativistic conditions [6] can be determined from the following:

$$\frac{fL}{n + 0.25} = 11.802\sqrt{1 - 1/(1 + V/511)^2}\ \text{Mc}, \tag{2}$$

where

V = beam voltage, kilovolts.

For convenience, (2) is plotted in Fig. 2.[1] Since the frequencies which yield negative resistance occur in narrow bands [2–4], (2) gives only approximate values.

In the Stanford klystron, $D = 1.25$ inches, $V = 400$ kv and the drift tunnels were 3.94 and 7.88 inches long. Using Figs. 1 and 2, the data shown in Table I was obtained. The frequencies below 5540 Mc cannot propagate in the 1.25-inch diameter tunnel. This tabulation leads to the conclusion that the 5770-Mc oscillation is associated with the $m=1$ and $n=2$ conditions in the shorter drift tunnel.

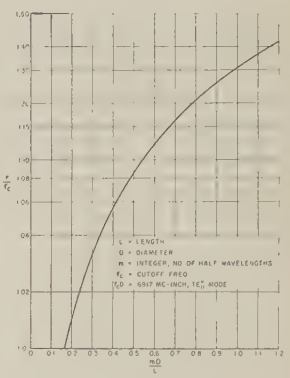


Fig. 1—Normalized resonant frequency of $TE_{11}°$ mode in circular drift tunnel.

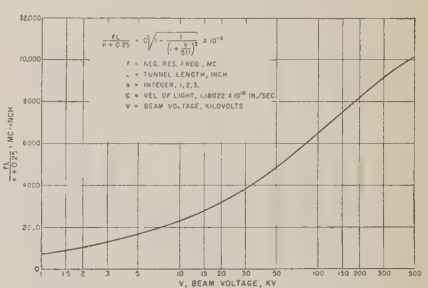


Fig. 2—Negative resistance frequencies in drift tunnel.

TABLE I

Tunnel Length		3.94-inch	7.88-inch
Tunnel Resonant Frequencies	$m=1$	5740 Mc	5590 Mc
	$m=2$	6300	5740
	$m=3$	7150	5985
Negative Resistance Frequencies	$n=1$	3100 Mc	1550 Mc
	$n=2$	5580	2790
	$n=3$	8120	4060
	$n=4$	—	5260
	$n=5$	—	6500

It appears that a large ratio of beam-to-tunnel diameters will yield a larger magnitude of negative resistance than will a small ratio and, hence, larger beams will more likely cause oscillations. A stronger longitudinal magnetic focusing field will reduce the amount of transverse beam displacement which in turn reduces the value of negative resistance. The Q of the tunnel resonant mode is also significant, and proximity to cutoff will result in a lower Q. A comprehensive analysis of the problem, although desirable, is beyond the scope of the present paper.

There is little question that these spurious oscillations with large amplitudes can adversely affect the performance of a klystron since the beam is coupled to both fundamental and spurious frequencies. The adverse effect may be phase and amplitude in-

* Received by the IRE, April 11, 1961.

[1] Full-size copies of the original with fine grid may be obtained from the author.

stability at the fundamental frequency. It is also conceivable that beam interception may increase, and the maximum RF efficiency would undesirably decrease.

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Noise in Beam-Type Parametric Amplifiers*

Beam-type parametric amplifiers employing separate input and output couplers or transducers are matched and unconditionally stable.[1] The reason, as is well known, is that the beam passively loads the transducers and is capable of carrying signal power only in the direction of drift. Thus the combination of beam and properly matched lossless transducers can be thought of as a perfect isolator.[2] The property of an isolator radiating thermal noise only in the direction of isolation is preserved, since the input transducer strips existing fast wave noise from the beam and sends it to the generator load. Ideally, no beam noise appears in the output transducer.

The purpose of this letter is to point out that the above picture must be modified to include a small frequency-dependent forward attenuation which arises because of the finite electron temperature and size of the beam. The following comments will be restricted to the transverse beam modes in O-type geometry. The culprit in the following model is the axial velocity spread. Signal power is transferred to a mode on the beam by a transducer and is distributed among a large number of beamlets, each associated with a different axial velocity class. As a result of the variation in velocities, a phase slip occurs among the beamlets which decreases the available signal power; that is, the power can no longer be completely coupled out of the beam. This is equivalent to attenuation. At the same time, noise appears on the beam at a rate which depends on the intrinsic noise temperature of the mode in question and the amount of attenuation. Lea-Wilson[3] and Kompfner[4] have noted that an axial velocity spread will introduce noise into the cyclotron wave.

We find that the attenuation $\alpha(l)$ for a beam that has drifted a distance l is given by

$$\alpha(l) = \left| \sum_{n=1}^{N} (I_n/I_0) \exp - i\beta_n l \right|^2 \qquad (1)$$

in which I_0 is the total beam current, I_n is the current of the nth beamlet, β_n is the propagation constant of the mode determined from the velocity of the nth beamlet, and N is the total number of velocity classes or beamlets.

The noise temperature of the beam at l is found to be

$$T(l) = \alpha(l)T(0) + [1 - \alpha(l)]T_i \qquad (2)$$

in which $T(0)$ is the noise temperature at $l=0$ and T_i is the intrinsic noise temperature for the mode in question. For the cyclotron modes $T_i=(\omega/\omega_c)T_{e\perp}$ in which ω is the angular noise frequency, ω_c is the electron cyclotron frequency and $T_{e\perp}$ is the transverse electron temperature. For the synchronous modes, $T_i=m\omega\omega_c D^2/8k$ for a uniform cylindrical beam of diameter D, in which m is the electron mass and k is Boltzmann's constant. The above expressions are valid for beams whose diameter is small compared to the wavelength of the transverse mode. Eq. (2) follows from consideration of beam dynamics and is identical to the expression for a transmission line attenuator at temperature T_i.

The noise temperature of the beam as it leaves the gun is not necessarily equal to T_i, although the noise temperature immediately in front of the cathode equals T_i, as has been shown by Adler and Wade[5] for cyclotron waves. T_i is invariant for slow changes in magnetic field and increases for rapid changes.[6]

The attenuation has been evaluated for three cases:

Case I. Thermal Axial Velocity Spread

$$\alpha(l) = [1 + (kT_{e\|}/mv_0^2)^2\beta_0^2 l^2]^{-1} \qquad (3)$$

in which $T_{e\|}$ is the longitudinal electron temperature, v_0 is the average drift velocity of the beam and β_0 the average propagation constant; $\beta_0=(\omega-\omega_c)/v_0$ for the cyclotron modes, $\beta_0=\omega/v_0$ for the synchronous modes.

Case II. Potential Depression Resulting From Space Charge

$$\alpha(l) \simeq \sin^2\theta/\theta^2, \quad \theta = \beta_q^2 D^2 \beta_0 l/32 \qquad (4)$$

in which $\beta_q=\omega_q/v_0$, ω_q being the plasma frequency.

Case III. Single-Anode Plane-Parallel Gun

$$\alpha(l) \simeq \sin^2\phi/\phi^2, \qquad \phi = 4\pi\theta. \qquad (5)$$

In most cases, thermal velocity spreads produce the largest attenuation. In all cases, $1-\alpha$ increases for increasing relative velocity spread.

Note that in degenerate Adler tubes[1] for which $\beta_0=0$, at centerband, there is no appreciable attenuation arising from velocity spread. If the magnetic field is not perfectly uniform, noise from this source can be observed since β_0 is not everywhere zero. Ashkin[7] has observed noise which can be attributed to this effect for a low-drift energy beam (<2 ev).

In nondegenerate amplifiers for which at least one of the signal or idler waves has $\beta_0\neq 0$, the noise arising from axial velocity spread may not be trivial.[8] One obvious solution is an increase of the beam drift energy since the relative velocity spread decreases. However, this can be carried only so far since the pumping process converts synchronous wave noise into cyclotron wave noise in an amount proportional to beam drift energy. This follows from the known fact that the increase in the input noise temperature of the amplifier from the synchronous wave mixing is

$$\Delta T = (Xv_0/L\omega_c)^2[T(\omega_s) + T(\omega_i)(\omega_s/\omega_i)] \qquad (6)$$

in which $T(\omega_s)$ and $T(\omega_i)$ are the noise temperatures of the slow synchronous wave at the signal and idler frequency and L is the pump length. The quantity X is given by $X=\cosh^{-1}\exp(G/8.68)$, in which G is the decibel gain in the quadrupole section; $X=3$ for $G=20$ db. The factor $(Xv_0/L\omega_c)^2$ is of order 10^{-3} in Ashkin's tube[7] and 10^{-2} in Adler's tube.[1] In either case, the noise contribution should be of order 10°K.

It is worth noting from (2) that the noise temperature of the transverse waves always can be made equal to the intrinsic noise temperature. This can be done by providing suitable low-velocity drift regions in which $B_0\neq 0$.

One can use the beamlet concept to compute the increase in input noise temperature which results when electrons, because of their thermal velocity spread, are pumped unequally as proposed by Ashkin.[7] For $\beta_0=0$ it can be shown that

$$\Delta T = \tfrac{1}{4}X^2 \tanh^2 X[2kT_e/mv_0^2]^2 T_i. \qquad (7)$$

For Ashkin's tube with a 10-volt beam and $kT_e=0.1$ ev, $\Delta T\cong 2\times 10^{-4}\ T_i$. Since for the cyclotron waves $T_i\simeq 10^3$°K, $\Delta T\simeq 0.2$°K. For Adler's tube, with a 3.8-ev beam, $\Delta T\simeq 2$°K.

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* Received by the IRE, April 24, 1961.

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Pull-In Frequency of the Phase-Controlled Oscillator*

If a phase-locked oscillator is mistuned far enough to throw it out of lock, and the mistuning is then slowly decreased, a point is reached where the oscillator synchronizes with the input signal. The value of mistuning for which this occurs is called the pull-in frequency.

Recently, Rey[1] presented a derivation of the pull-in frequency of a phase controlled oscillator with a sinusoidal comparator. He assumes that, in the marginal asynchronous case, the time derivative of the phase error is zero when the phase comparator output is maximum.

Goldstein[2] analyzed the case of the sawtooth comparator with a phase lag filter (Fig. 1), and found the stable asynchronous mode with the lowest mistuning frequency. In this marginal mode, in general, the phase error approaches the comparator discontinuity with a nonzero, positive slope. The pull-in frequency derived by Goldstein is appreciably lower than that resulting from the zero slope assumption, except for the degenerate RC filter case ($R_2=0$). In this special case, the assumption is correct.

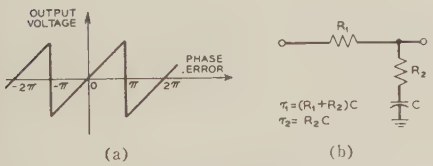


Fig. 1—(a) Sawtooth comparator. (b) Phase lag filter.

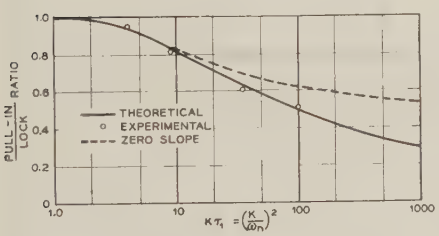


Fig. 2—Normalized pull-in frequency of the phase-controlled oscillator with a sawtooth comparator and phase lag filter. The damping ratio is unity.

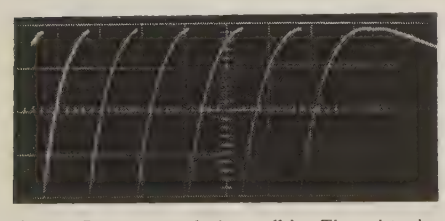


Fig. 3—Phase error during pull-in. The mistuning frequency has been slowly decreased below the pull-in frequency just before this picture was taken. The mistuning was constant during the time shown.

* Received by the IRE, March 6, 1961.

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An experimental investigation by Byrne has shown that Goldstein's values of pull-in are correct (Fig. 2), and that the marginal asynchronous mode has the properties predicted by him. When the mistuning is decreased below the marginal value, the mode becomes unstable. After passing through several discontinuities, the circuit synchronizes with the input signal (Fig. 3). The mode with zero slope was not observed. This mode is unstable.

We conclude that, for the case of the sawtooth comparator with a phase lag filter, the assumption of zero slope yields only an upper bound for the pull-in range, and Goldstein's analysis must be used instead.

We do not know whether a similar effect occurs in the case of the sinusoidal comparator, but the possibility should be recognized. Rey has published experimental data which indicates that any error due to his assumptions is small in the region investigated.

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Fourier Series Derivation: A Comment*

Gadsden,[1] in a rebuttal to a note by Ferris,[2] invites comment on the validity of a term-by-term inversion of an infinite series of transforms. This is done very simply in the light of distribution theory[3] which, of course, should have been used by both authors all along. Their quibbles and difficulties with such worn out problems show how little of the modern theory of transforms is known by the people who would most benefit by it.

The famous theorem that, in distribution theory, all convergent infinite series of integrable functions, measures, and/or distributions are always differentiable term by term, is sufficient proof of the validity of the term-by-term inversion. In any case, one can directly derive the Fourier series from the Fourier transform. A periodic function is of the form

$$T = (Y_0 - Y_h)T_* \sum_n \delta_{nh} \qquad (1)$$

where Y_h is Heaviside's step function starting at x equal h, and δ_{nh} is Dirac's delta function placed at x equal nh. The star is for convolution product.

Now the Fourier transform of the Dirac delta function is

$$F\delta_h(x) = \exp - 2i\pi(h\cdot y), \qquad (2)$$

so that

$$F\left(\sum_n \delta_{nh}(x)\right) = \sum_n \exp - 2i\pi(nh\cdot y). \qquad (3)$$

But the right-hand side is well known to be

$$\sum_n \exp - 2i\pi(nh\cdot y) = h\sum_n \delta_{nh}(y), \qquad (4)$$

thus

$$F\left(\sum_n \delta_{nh}(x)\right) = \frac{1}{h}\sum_n \delta_{nh}(y). \qquad (5)$$

The Fourier transform of (1) is thus

$$FT = \frac{1}{h}\left(\sum_n \delta_{nh}(y)\right) F((Y_0 - Y_h)T), \qquad (6)$$

or

$$FT = \frac{1}{h}\sum_n \delta_{nh}(y) \cdot\left(\int_0^h T(\exp - 2i\pi(x\cdot nh))dx\right). \qquad (7)$$

The integrals are independent of y and x. They are constants in the inverse transformation. Because the inverse Fourier transform of the Dirac delta function is

$$\bar{F}\delta_h(y) = \exp 2i\pi(h\cdot x), \qquad (8)$$

one obtains from (7)

$$T = \frac{1}{h}\sum_n (\exp 2i\pi(x\cdot nh)) \cdot\left(\int_0^h T(\exp - 2i\pi(x\cdot nh))dx\right), \qquad (9)$$

which is the usual form of the Fourier series.

The integrals in (9) having a finite domain of integration will be meaningful for any integrable function, measure or distribution T. The right-hand side of (9) must, however, be convergent when projected on the ϕ functions of the Class D defined as: all continuous functions with compact domains which are indefinitely differentiable, and such that the derivatives also belong to the class. The class must also be endowed with a pseudotopology to the effect that a convergent sequence of ϕ functions can be differentiated term by term any chosen number of times, provided the domains of the ϕ functions are all subsets of the same compact subset of the continuum.[3]

Projecting (9) on a ϕ function

$$T(\phi) = \frac{1}{h}\sum_n\left[\int_R (\exp 2i\pi(x\cdot nh))\phi(x)dx\right] \cdot\left(\int_0^h T(\exp - 2i\pi(x\cdot nh))dx\right), \qquad (10)$$

with R for the continuum. The terms on the right-hand side are always meaningful. The series, however, must be convergent (equal to zero or to a finite value) for all ϕ's of the Class D. It is sufficient, however, to choose ϕ functions with quasi-punctual domains.

Finally, all trigonometric series are Fourier series. The ones which are not Fourier series of periodic integrable functions or measures are Fourier series of periodic distributions.

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* Received by the IRE, April 21, 1961.

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Traveling-Wave Maser with Instantaneous Bandwidths in Excess of 100 Mc*

An *S*-band traveling-wave maser has been operated with 3-db amplification bandwidths as great as 126 Mc centered at a frequency of 2280 Mc, with electronic gains greater than 16 db. The maser utilized a comb-type slow-wave structure loaded on both sides of the comb with $6\frac{1}{2}$ inches of X-ray oriented ruby of nominal 0.05 per cent chromium concentration. The external magnetic field was oriented at $\theta = 90°$ to the ruby c axis, and the helium bath temperature was 1.8°K.

These broad bandwidths, more than twice the nominal 60-Mc intrinsic linewidth of ruby,[1] were obtained by stagger-tuning the applied external magnetic field (H_{dc}). The staggered field causes the imaginary part of the magnetic susceptibility $\chi''(f)$, which is usually assumed to have a Lorentzian line shape, to broaden and take on a new effective shape dependent upon the distribution of the magnetic field. This results in a corresponding change in the maser gain vs frequency characteristic $G(f)$, since $G(f) = K\chi''(f)$, where $G(f)$ is the gain in db and K is a constant determined by the microwave propagating structure. An analysis of this technique has been independently presented by Ostermeyer.[2]

Photographs of oscilloscope displays of maser amplification bandwidth under increasing staggered-field conditions are shown in Fig. 1. The field staggering was accomplished by periodically shimming one of the pole pieces of an electromagnet with thin rectangular slabs of high-permeability material. The amplitude of the peak-to-peak field variations on the ruby were controlled by adjusting the proximity of the shimmed pole piece to the slow-wave structure. The average value of the external field for all the measurements was approximately 2.46 kilogauss, and the peak-to-peak variations were as high as 70 gauss. It should be pointed out that under homogeneous field conditions, the maser yielded net gains of 30 db (with a net reverse loss of 100 db), an instantaneous bandwidth of 21 Mc, and an electronic tuning range in excess of 240 Mc.[3]

A detailed bandwidth measurement of the trace shown in Fig. 1 (c) is plotted in terms of net gain in Fig. 2. It can be seen that a maximum net gain of 11 db is obtained with a 3-db bandwidth of 100 Mc. The structure loss was 7.5 db. This high structure loss was due, in part, to the magnetic broadening in some of the ferrite isolator disks produced by the inhomogeneous field.

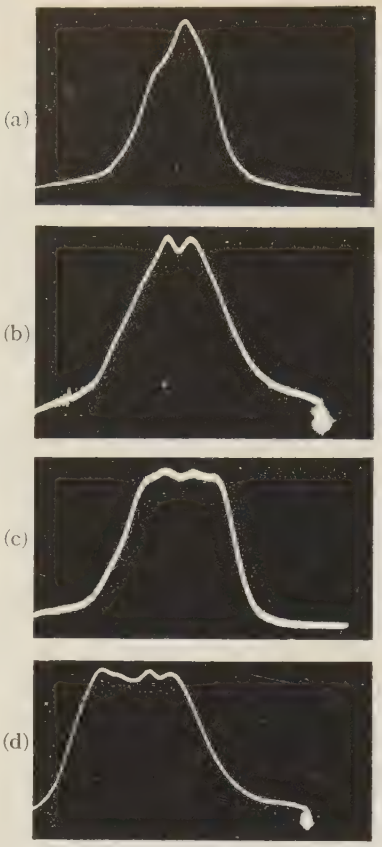


Fig. 1—Oscilloscope display of the maser amplification bandwidth under different field staggering conditions (center frequency≈2280 Mc). (a) 3-db bandwidth = 46 Mc; electronic gain = 25.5 db. (b) 3-db bandwidth = 58 Mc; electronic gain = 23.5 db. (c) 3-db bandwidth = 100 Mc; electronic gain = 18.5 db. (d) 3-db bandwidth = 126 Mc; electronic gain = 16.5 db.

It is believed that with proper ferrite disk design, this loss can be reduced.

All of the above broad bandwidth measurements were obtained with one CW pump source operating at a fixed frequency of 12.62 kMc. This single-frequency source of power sufficiently saturated the wings of the pump transition so that no serious bandwidth degradation effects occurred. A qualitative picture of the degree of wing saturation is shown in the plot of Fig. 3, where the relative gain of a similar maser (with a homogeneous field) is plotted as a function of signal frequency for a fixed CW pump frequency and optimized magnetic field.[4] From this curve, it can be seen that the signal can be tuned over a 120-Mc band before the gain decreases by 3 db. If maser bandwidths much greater than 120 Mc are desired with high gain-bandwidth efficiency, it might be necessary to employ two pump sources operating at different frequencies, or to use one pump source that is frequency modulated at a rate much greater than the pump-transition relaxation time.

It is worthwhile mentioning that two different stagger-tuned field configurations were successfully used.

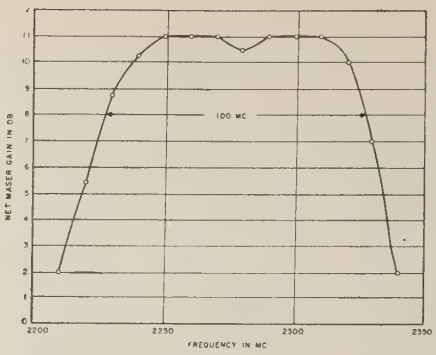


Fig. 2—Detailed amplification band of stagger-tuned TWM [see Fig. 1(c)].

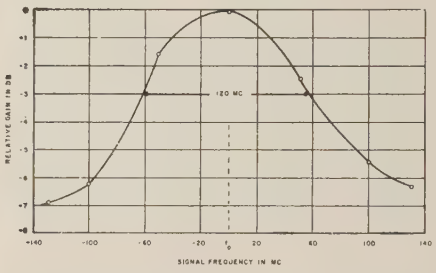


Fig. 3—Relative gain vs signal frequency for fixed pump frequency and optimized magnetic field. $f_0 = 2250$ Mc; $f_p = 12.65$ kMc; pump power = 200 mw; H_{dc} = optimized for maximum gain; $T_{bath} = 1.8°K$.

1) Periodic staggering along the direction of propagation.
2) A linear field variation perpendicular to the direction of propagation.

Either of the above configurations are desirable for low-noise considerations. (It would be undesirable to have a portion of the signal spectrum traveling through a significant length of slow-wave structure experiencing loss before being amplified.) In the first configuration, the periodic staggering effectively divides the structure into many sections, each of which yields gain to the entire signal spectrum. The second configuration has the effect of dividing the ruby into long parallel filaments, each filament yielding gain to a small portion of the frequency band over the entire length. It is believed that this latter technique is more effective in maintaining the maser low-noise properties.

It should also be pointed out that the conditions desired in the staggered field for broadbanding are a variation in the amplitude of the H_{dc} vector and an unperturbed angular orientation. When the angular orientation of the field varies, broadening is obtained but with the additional decrease in gain caused by the reduced transition probability. This is an expensive trade of gain for bandwidth. Unfortunately, in the experiments discussed in this note, a considerable amount of angular inhomogeneity was present. Further work is being done to correct this situation.

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* Received by the IRE, April 24, 1961. This work was supported in part by the USAF Aeronautical Systems Div., under Contract AF33(600)-38862.

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The Propagation of Wide-Band Signals Through the Ionosphere*

In connection with wide-band active satellite relaying techniques, consideration must be given to the dispersive characteristic of the ionosphere even at UHF. The phenomenon of Faraday rotations has already been studied in great detail by many including Millman[1] and Garriott.[2] We will, therefore, restrict our consideration here to the question of differential group delay across the frequency band.

For the evaluation of group delay, one can disregard the small effect due the earth's magnetic field and use the following formula for the refractive index of ionosphere.

$$n^2 = 1 - (f_p/f)^2, \tag{1}$$

where n is the refractive index, f_p is the plasma frequency and f is the operating frequency. The plasma frequency f_p depends on certain universal constants (such as charge and mass of the electron) and on the number density of the electrons. As might be expected, it is highly variable. It is characterized by reasonably regular diurnal, seasonal and sunspot cycle variations as well as highly irregular, random fluctuations. A fair estimate of the range of values for f_p through the regular ionosphere is 3 Mc to 12 Mc. For the frequencies of interest,

$$n \cong 1 - f_p^2/2f^2. \tag{2}$$

The propagation constant k is given by $k = k_0 n$ where $k_0 (= \omega/c)$ is the free-space propagation constant. The total phase change ϕ between transmitter and receiver is

$$\phi = k_0 \int n ds = \frac{\omega}{c} \int n ds, \tag{3}$$

where the integral is taken along the path from transmitter to receiver. The group delay τ through the ionosphere is then

$$\tau = \frac{d\phi}{d\omega} = \frac{1}{c} \int [1 + f_p^2/2f^2] ds$$
$$= \frac{R}{c} + \frac{1}{2cf^2} \int f_p^2 ds, \tag{4}$$

where R is range between transmitter and receiver. A fairly simple approximate expression for the group delay $\Delta\tau$ across the band Δf can be obtained by taking the total differential on both sides of (4),

$$\Delta\tau = \frac{\Delta f}{cf^2} \int f_p^2 ds. \tag{5}$$

Until the problem can be studied in finer detail, it would appear that a reasonable requirement for the maintenance of signal fidelity is that $\Delta\tau \ll 1/\Delta f$, where Δf is of the order of the RF bandwidth, since the delay $\Delta\tau$ occurs at RF. Actually, Δf may have to be defined differently for different modes of modulation. The criterion for maintenance of fidelity (or no distortion) can, therefore, be written

$$\Delta\tau\Delta f = \frac{(\Delta f)^2}{cf^2} \int f_p^2 ds \ll 1. \tag{6}$$

This criterion is very conveniently a function of three independent factors, namely, Δf, f, and $\int f_p^2\, ds$. The last of these is a characteristic of the ionosphere only. Because the above criterion is very sensitive to frequency (f^{-3}), changes in operating frequency by factors of two or three can bring one from regions with noticeable distortion to regions of negligible distortion, and vice versa.

To obtain a quantitative estimate for the parameter $\Delta\tau\Delta f$, we approximate the integral in (6) by $\langle f_p^2 \rangle R$, where $\langle f_p^2 \rangle$ is the average value of the square of plasma frequency in the ionosphere and R is the slant range through the ionosphere. With this approximation, (6) gets simplified still further.

$$\Delta\tau\Delta f \cong \frac{(\Delta f)^2}{cf^2} \langle f_p^2 \rangle R. \tag{7}$$

For low angles of elevation (*i.e.*, when the satellite is near the horizon) the slant range through the ionosphere may approach 2000 km. A typical number for the average plasma frequency f_p is about 7 Mc. Thus, for one television channel occupying roughly a 10-Mc bandwidth (both sidebands) operating at 1000 Mc, (7) yields $\Delta\tau\Delta f = 3 \times 10^{-2}$. This is indeed small compared to unity. However at 400 Mc, $\Delta\tau\Delta f$ would be almost 0.5, and distortion may turn out to be a problem at this frequency.

To obtain a better estimate of the integral in (6), use was made of an earlier report[1] that in effect evaluated $\int f_p^2 ds$. From the curves in Fig. 24 and Fig. 28 of the report (corresponding to daytime ionospheric conditions and low angles of incidence), the estimate for $\Delta\tau\Delta f$ at 400 Mc varies from 0.4 to 2.0, depending on the assumptions one makes about the structure of the ionosphere. This is consistent with the simple expression in (7) derived earlier.

It is well known in the communication art that channel capacity is related to both bandwidth and signal-to-noise ratio and that, within limits, one of these can be traded for the other. Since power is at a premium in an active satellite, some thought is going into the development of very wide band systems for active satellite relaying. Although high-modulation index FM is not one of the most efficient modulation schemes, it is one of the simplest. For a modulation index of ten, one TV channel would occupy approximately 100 Mc of RF bandwidth. For this case, $\Delta\tau\Delta f$ increases one hundredfold over the previous calculation, and even at 1000 Mc, distortion would become a serious problem. Under these conditions, frequencies above 3500 Mc may be needed. If one looks ahead several years to satellites having the capability of handling the baseband equivalent of several TV channels (the entire baseband FM modulated on one carrier), the problem of delay distortion through the ionosphere will become even more serious.

Relaying to synchronous satellites (*i.e.*, those at a height of 22,300 miles, which remain stationary over a fixed point on earth) does not appear to introduce any additional difficulty. Although the range through the exosphere (that part of the earth's atmosphere which lies beyond the ionosphere) to a synchronous satellite is greater than the range through the ionosphere by a factor of 20, $\langle f_p^2 \rangle$ in the exosphere is reduced from that in the ionosphere by a factor of at least 10^{-2}.

One final note of caution may be in order at this point. The previous discussion restricted itself to a reasonably regular ionosphere. Very intense solar flares occasionally may disrupt the ionosphere sufficiently so as to introduce greater delays than those presented here, especially during sunspot maxima. It would, therefore, behoove us to design some satellite tests in the not too distant future to obtain quantitative estimates for group delay distortion in wideband systems.

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Noise Measure of Lossy Tunnel-Diode Amplifier Stages*

The influence of losses on the noise figure of tunnel-diode amplifiers has been dealt with by several authors.[1] Some [1]–[5] have taken only circuit losses into account, others [6], [7] have included losses caused by the series resistance of the diode only. The author [8] has included both types of losses, but his result was obtained for a series circuit, which is not necessarily stable. Though this may not alter the results, it is worthwhile to repeat the calculation for the stable parallel circuit by a slight extension of Nielsen's approach [7].

First consider the lumped circuit case. The extension of Nielsen's equivalent circuit [7] is shown in Fig. 1. The negative conductance of the junction proper is $-G_d$; $-G_d''$ is the transformed junction conductance as seen from the diode terminals, G_s'' is the input conductance caused by the diode series resistance R_s, G_c is the circuit conductance, G_a is the source conductance, B'' the apparent diode susceptance as seen between the terminals, and B the circuit susceptance needed to tune to the desired

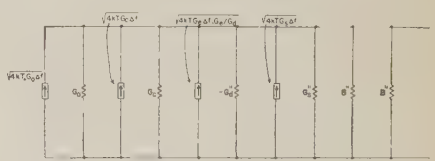


Fig. 1.

* Received by the IRE, April 14, 1961.

[1] Many authors, *e.g.*, Chang [1], [2], Sommers, *et al.* [9], and Tiemann [10] count the noise of the load as belonging to the tunnel-diode stage. That problem will be dealt with elsewhere [12]. Trambarulo [11] has reported microwave values of the noise figure.

frequency. The values of $-G_d''$, G_s'', and B'' can be obtained from Nielsen's work [7]. The circuit is stable if $(G_a+G_c+G_s'')>G_d''$; it will be assumed that this condition is satisfied.

The conductances G_a, G_c and G_s'' show thermal noise; the noise associated with G_d'' is represented by a current generator $\sqrt{4kTG_c''\Delta f(G_e/G_d)}$, where G_e is the equivalent noise conductance of the junction proper. $G_e=(eI_0/2kT)$, if the junction current shows full shot noise.

For $(G_a+G_c+G_s'')>G_d''$, the available gain is

$$g_{av}=\frac{G_a}{(G_a+G_c+G_s''-G_d)}, \tag{1}$$

and the noise figure F is

$$F=1+\frac{4kTG_c\Delta f+4kTG_d''\Delta f\dfrac{G_e}{G_d}+4kTG_s''\Delta f}{4kT_0G_a\Delta f}$$

$$=1+\frac{T}{T_0}\left(G_c+G_d''\frac{G_e}{G_d}+G_s''\right)\frac{1}{G_a}. \tag{2}$$

The noise measure M of the circuit is

$$M=\frac{F-1}{1-1/g_{av}}=\frac{T}{T_0}\left|\frac{\dfrac{G_e}{G_d}G_d''+G_c+G_s''}{G_d''-G_c-G_s''}\right|$$

$$=\frac{T}{T_0}\left|\frac{\dfrac{G_e}{G_d}+\dfrac{G_c}{G_d''}+\dfrac{G_s''}{G_d''}}{1-\dfrac{G_c}{G_d''}-\dfrac{G_s''}{G_d''}}\right|. \tag{3}$$

This expression is useful only if $(G_c+G_s'')<G_d''$, for otherwise the amplifier does not have gain.

For the lossless case $G_c=0$, $R_s=0$ (hence, $G_s''=0$ and $G_d''=G_d$), the noise measure becomes

$$M=M_0=\frac{T}{T_0}\frac{G_e}{G_d}, \tag{3a}$$

corresponding to what is obtained by Sommers, *et al.*, [9] and by Tiemann [10]. For $G_c=0$ but $R_s\neq 0$ the result obtained is identical with the one obtained by Penfield [6] and by Nielsen [7]. For $G_c\neq 0$ and $R_s=0$ (and hence, $G_s''=0$ and $G_d''=G_d$), the result corresponds to the one found by Chang [1], [2], when the contribution of the noise of the loud conductance G_L is eliminated from the latter.[2] For $G_c\neq 0$ and $R_s\neq 0$, the result can be transformed into what was calculated by van der Ziel [8]. Nielsen has expressed the noise figure for high gain very conveniently in terms of the diode cutoff frequency. This is easily done for the term $(1-G_s''/G_d'')$, but it is more difficult if the term G_c/G_d'' is taken into account.

The same result (3) is obtained for a reflection-type amplifier using a circulator. Fig. 2 shows the circuit; for the sake of simplicity the noise sources are omitted. Let the notation be the same as before and let G_a again be the source impedance (=transformed characteristic impedance of the line). Following Hines and Anderson [3], the value of the gain that takes the place of the available gain in the noise measure M, is the square of the reflection coefficient of the line:

$$g_p=\left(\frac{G_a-G_c-G_s''+G_d''}{G_a+G_c+G_s''-G_d''}\right)^2. \tag{4}$$

The noise figure F is[3]

$$F=1+\frac{T}{T_0}\frac{4G_a}{(G_a-G_c-G_s''+G_d'')^2}\cdot\left(\frac{G_e}{G_d}G_d''+G_c+G_s''\right). \tag{5}$$

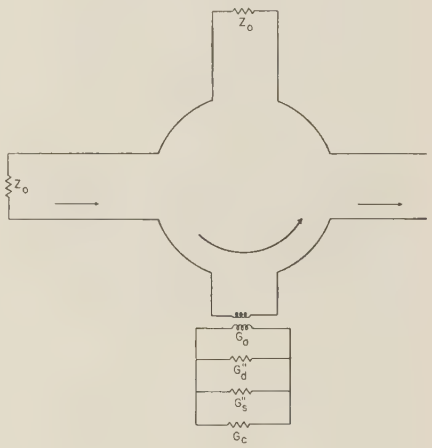


Fig. 2.

When it is observed that g_p corresponds to the expression g_{av} of the previous case, so that $M=(F-1)/(1-1/g_p)$, and the corresponding substitutions are made, one obtains again (3). It is noted that (3) shows considerable similarity with what is obtained for a lossy, distributed, active line [13].

For $R_s=0$ (and hence $G_s''=0$, and $G_d''=0$), (4) and (5) agree with the results obtained by Hines and Anderson [3], Jariv, *et al.* [4], and with Sie's corrected results [5]. Jariv, *et al.*, could express their result in terms of the power gain g_p and of measurable Q factors of the circuit. This becomes more difficult if the losses caused by the series resistance of the diode are taken into account.

The expression

$$F=F_\infty=M+1 \tag{6}$$

corresponds to the noise figure for infinite gain. For the particular case $T=T_0$, (6) reduces to

$$F_\infty=\frac{1+G_e/G_d}{1-G_c/G_s''-G_s''/G_d''}; \tag{6a}$$

it is useful for $(G_c+G_s'')<G_d''$, for otherwise the amplifier does not have gain. For the lossless case ($G_c=0$, $R_s=0$), (6a) reduces to the well-known expression

$$F_\infty=1+\frac{G_e}{G_d}. \tag{6b}$$

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Noise Measure of Distributed Negative-Conductance Amplifiers*

Haus and Adler [1] have introduced the concept of the noise measure M of an amplifier stage by the definition

$$M=\frac{(F-1)}{(1-1/g_{ex})}, \tag{1}$$

where F is the noise figure of the stage and g_{ex} is the exchangeable gain. This note shows how their discussion has to be modified for distributed negative-conductance circuits in which the characteristic impedance Z_0 of the circuit has a reactive part. It formalizes the procedure developed by Hines [2] for the distributed tunnel-diode problem. Chang [3] has discussed the general theory of a negative-resistance transmission-line amplifier with distributed noise sources from a somewhat different point of view.

[2] Instead of M, many authors use the expression $(M+1)$, the noise figure for infinite gain. After correcting Chang's result for the effect of the load conductance G_2, his expression corresponds to $(T_0/T)M(1-G_c/G_d)$.

[3] The noise figure is here defined as $F=1+P_d/P_a$, where P_d is the noise power delivered to the line by the diode and the circuit, and $P_a=kTdfg_p$ is the reflected noise power coming from the source.

* Received by the IRE, April 14, 1961.

If a signal source, or the output of an amplifier, is represented by an EMF E and an internal impedance Z, then the exchangeable power P_e is defined as

$$P_e = \frac{1}{4}\frac{EE^*}{(Z+Z^*)}, \tag{2}$$

where the asterisk denotes the conjugate complex quantity. If Z has a positive real part, P_e represents the power that can be pushed into a (passive) matched load Z^*. If Z has a negative real part, P_e is negative and represents the power that can be pushed into the source by a matched (active) load Z^*. One can thus define the exchangeable source power P_{es} and the exchangeable outpower P_{eo} of an amplifier stage. The exchangeable gain g_{ex} is then defined as

$$g_{ex} = \frac{P_{eo}}{P_{es}}, \tag{3}$$

and the noise figure F is defined by

$$F = \frac{\text{exchangeable output noise power}}{g_{ex}kTdf}. \tag{4}$$

Difficulties arise, however, in distributed active circuits. To avoid reflections, the active distributed line is terminated in its characteristic impedance Z_0 on both sides of the line. If Z_0 is real and positive, the termination into Z_0 represents a maximum power transfer. If Z_0 has a reactive part, this is no longer the case, for the line should now be terminated in Z_0 instead of in Z_0^*. This means that definitions (1)–(4) have to be modified.

The most convenient way to do so is to put the discussion on a *current* (not a *power*) basis. Let an active distributed line of length l be terminated on both ends by its characteristic impedance $Z_0=(R_0+jX_0)$, and let $\gamma=(-\alpha+j\beta)$ be the propagation constant of the line. If i_i and i_o are the input and output current, respectively, then $i_o=i_ie^{-\gamma l}$. Hines [2] defines the square of the current gain $|i_o/i_i|$ as the *internal gain* g_i of the active line:

$$g_i = \left|\frac{i_o}{i_i}\right|^2 = e^{2\alpha l}. \tag{5}$$

The noise figure F is defined as

$$F = 1 + \frac{\text{mean-square output noise}}{\text{current due to line}} - \frac{}{\text{mean-square output noise}}. \tag{6}$$
$$\text{current due to source}$$

To calculate F, the noise sources are now introduced. Let a section of the line of length dz have a series impedance $(R_1+jX_1)dz$ and a parallel admittance $(G_1-G_d+jB_1)dz$, where R_1, G_1 and $-G_d$ are the loss resistance, the loss conductance and the negative conductance per unit length, respectively. The noise of a section of length dz can be represented by an EMF $\sqrt{4kTR_1dfdz}$ in series with the line section and by independent current generators $\sqrt{4kTG_1dfdz}$ (thermal noise of G_1) and $\sqrt{4kTG_ndfdz}$ (G_n being the equivalent noise conductance of the noise of the negative conductance $-G_d$) in parallel with the section. The characteristic impedance Z_0 and the propagation constant γ of the line are defined as

$$Z_0 = R_0 + jX_0 = \frac{R_1 + jX_1}{G_1 - G_d + jB_1};$$

$$\gamma = -\alpha + j\beta = (R_1 + jX_1)(G_1 - G_d + jB_1). \tag{7}$$

The mean-square output noise current of the source is

$$\overline{i_0^2} = kT_0dfR_0/|Z_0|^2. \tag{8}$$

The noise contributions of $-G_d$, G_1 and R_1 are, respectively,

$$\overline{i_{G_d}^2} = kTG_ndf\left(\frac{g_i-1}{2\alpha}\right), \tag{9}$$

$$\overline{i_{G_1}^2} = kTG_1df\left(\frac{g_i-1}{2\alpha}\right), \tag{10}$$

$$\overline{i_{R_1}^2} = \frac{kTR_1df}{|Z_0|^2}, \tag{11}$$

as is found by taking the contribution of each section dz and then integrating over the length l of the line (compare Hines [2]). Substituting (8)–(11) into (6) gives

$$F = 1 + \frac{T}{T_0}\left(\frac{g_i-1}{g_i}\right)\left(\frac{|Z_0|^2G_d}{2\alpha R_0}\right)\cdot\left[\frac{G_n}{G_d} + \frac{G_1}{G_d} + \frac{R_1}{G_d|Z_0|^2}\right]. \tag{12}$$

If the losses of the distributed line are small, that is, if $R_1 \ll X_1$ and $G_1 \ll G_d$, one finds

$$\frac{2\alpha R_0}{G_d|Z_0|^2} \simeq \left[1 - \frac{G_1}{G_d} - \frac{R_1}{G_d|Z_0|^2}\right] = 1 - \frac{G_1}{G_d} - \frac{G_1'}{G_d}, \tag{13}$$

where $G_1' = R_1/|Z_0|^2$ is the distributed equivalent conductance of the distributed series resistance R_1 of the line. Eq. (12) may thus be written

$$F = 1 + \frac{T}{T_0}\left(1 - \frac{1}{g_i}\right)\frac{\left[\frac{G_n}{G_d} + \frac{G_1}{G_d} + \frac{G_1'}{G_d}\right]}{\left[1 - \frac{G_1}{G_d} - \frac{G_1'}{G_d}\right]}. \tag{12a}$$

The noise measure M of the active line is now defined as

$$M = \frac{F-1}{(1-1/g_i)} = \frac{T}{T_0}\frac{\left[\frac{G_n}{G_d} + \frac{G_1}{G_d} + \frac{G_1'}{G_d}\right]}{\left[1 - \frac{G_1}{G_d} - \frac{G_1'}{G_d}\right]}. \tag{14}$$

For the lossless case ($R_1=0$, $G_1=0$),

$$M = M_0 = \frac{T}{T_0}\frac{G_n}{G_d}. \tag{14a}$$

The result for the lossless case is completely equivalent with the noise measure of the lossless lumped-circuit case, whereas the result for the lossy active line is fully comparable to that of the lossy lumped-circuit case [4].

It is thus seen that (6) is the most convenient expression for the noise figure F, and that

$$M = \frac{F-1}{1-1/g_i} \tag{15}$$

is the proper definition for the noise measure M of the distributed active circuit. For the case of real positive Z_0, (15) reduces to (1), as expected.

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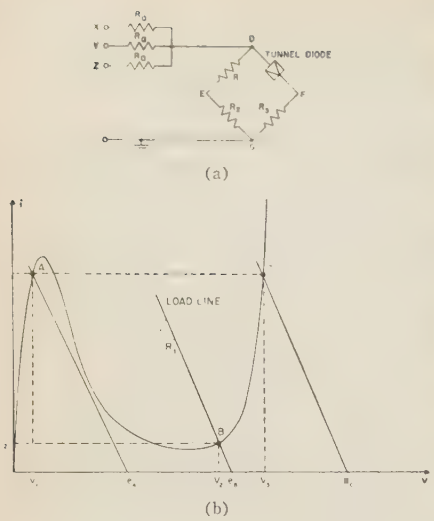
Full Binary Adder With One Tunnel Diode*

A basic operation performed by the arithmetic section of a digital computer is the addition of binary numbers. This is commonly done by a full binary adder consisting of 16 diodes arranged in four levels of logic serially-driven. The circuit shown in Fig. 1(a) performs full binary addition by employing a single tunnel diode and three resistors in a Wheatstone bridge network. Fig. 1(b) illustrates a tunnel diode I-V characteristic and the operating points indicated by A, B, and C to be achieved by the various values V for one, two and three inputs, respectively. The circuit is voltage-driven. When a voltage pulse V_a is applied to any or all of the inputs X, Y, Z, the voltages V_{FG} and V_{EF} have the logical properties of SUM and CARRY, respectively, provided suitable choices of V_a, R_1, R_2 and R_3 are made for a given R_a and tunnel diode. The circuit can be reduced by Thevenin's theorem to a voltage e applied in series with resistance R_t and the tunnel diode, where R_t is the equivalent resistance of the circuit.

The required operating points A, B and C can be established by e_A, e_B, and e_C (with $e_A:e_B:e_C=1:2:3$, since e is proportional to V_a), and an appropriate choice of R_t. To fulfill the logical functions, R_1 is chosen equal to V_1/i_1 and R_2 is made equal to R_3. R_2 is now the disposable parameter available to establish the correct value of R_t.

The voltage developed across R_2 has the required properties of the SUM since it will be equal to i_1R_2 for both one and three in-

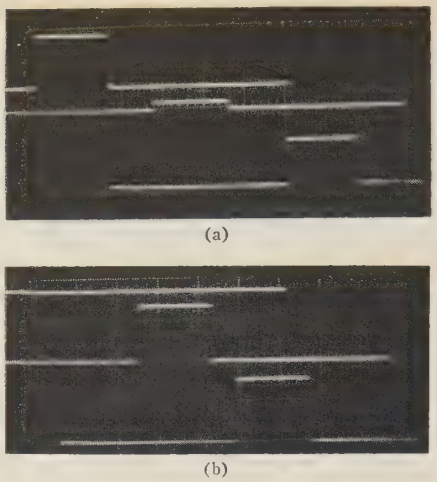
* Received by the IRE, April 11, 1961; revised manuscript received, May 4, 1961.



(a)

(b)

Fig. 1—(a) Full binary adder circuit. (b) Tunnel-diode characteristics showing the load line and operating points A, B and C.



(a)

(b)

Fig. 2—Oscilloscope display of (a) the SUM output, 0.1 v/cm vertically, (b) the CARRY output, 0.2 v/cm vertically. In each picture the upper curve is for a single input, the center curve for two inputs and the lower curve for three inputs. The horizontal scale is 5 μsec/cm.

puts, while it has a considerably lower value of i_2R_2 for two inputs. A suitable tunnel diode with a high peak-to-valley ratio can make the SUM output with two inputs 10–20 times below that for one and three inputs. An output corresponding to the CARRY is obtained between terminals E and F of the bridge. With one input, the tunnel diode presents resistance $V_1/i_1=R_1$ to the bridge which is thus balanced, and no output appears between C and D. With two or three inputs present, the resistance that the tunnel diode presents to the bridge is V_2/i_2 and V_3/i_1, respectively. In both cases this is greater than R_1, and the bridge is unbalanced so that there is a voltage output between E and F. These SUM and CARRY outputs fulfill the complete requirements of a full binary adder.

The design analysis will now be outlined. Since there is a broad valley in the tunnel-diode characteristic, state B is certain to be at a current i_2 close to the minimum valley current. It can readily be shown that

$$V_a = v + iR_2 + \left[i + \frac{v + iR_2}{R_1 + R_2}\right]\frac{R_a}{3}, \quad (1)$$

where v is the voltage across the tunnel diode for current i through it. For state A, $V_a=V/3$, $v=V_1$, $i=i_1$, and for state C, $V_a=V$, $v=V_3$, $i=i_1$. Substituting into (1) and eliminating V yields

$$\frac{R_a}{3(R_1+R_2)}\left[R_1 + 2R_2 - \frac{V_3 - 3V_1}{2i_1}\right] = \frac{V_3 - 3V_1}{2i_1} - R_2. \quad (2)$$

Since R_a is necessarily positive, the range of R_2 is given by

$$R_1 + 2R_2 \geq \frac{V_3 - 3V_1}{2i_1} \geq R_1. \quad (3)$$

The left-hand equality corresponds to $R_a\to\infty$ and the right-hand equality to $R_a\to 0$. Since R_1, V_3, V_1 and i_1 are all given by the diode characteristic (choosing i_1 as close to the peak current as is practical with regards to possible component variation), the I-V characteristic of the tunnel diode and source impedance determine the necessary value of R_2.

The carry K is found to be

$$K = \frac{R_2}{R_1 + R_2 + \frac{1}{3}R_a}\cdot\left[V_a - i(R_1 + R_2 + \tfrac{2}{3}R_a)\right]. \quad (4)$$

Since in state A, $V_a=V/3$ and $K=0$, (4) can be written

$$K = \frac{R_2}{R_1 + R_2 + \frac{1}{3}R_a}\left(V_a - \tfrac{1}{3}V\,\frac{i}{i_1}\right). \quad (5)$$

For state B, $V_a=2/3\,V$ and $i=i_2$, and for state C, $V_a=V$, $i=i_1$, thus

$$K_B = \frac{\left(2 - \frac{i_2}{i_1}\right)VR_2}{R_a + 3R_1 + 3R_2}, \quad (6)$$

and

$$K_C = \frac{2VR_2}{R_a + 3R_1 + 3R_2}. \quad (7)$$

Also the sum

$$S_A = S_C = \frac{VR_2}{2R_a + 3R_1 + 3R_2}. \quad (8)$$

Experimental results have been obtained using a 1.25-ma peak-current germanium tunnel diode, IN2939, in the circuit shown in Fig. 1(a) with $R_2=120\Omega$, $R_1=39\Omega$ and $R_a=120\Omega$. A pulse generator was used to simulate the required conditions so that positions of a switch could then simulate the simultaneous arrival of one, two or three pulses to X, Y and Z. The operating points of Fig. 1(a) were then A: $i_1=1.1$ ma, $V_1=45$ mv; B: $i_2=0.15$ ma, V_2 in the valley of the tunnel-diode characteristic, C: $i_1=1.1$ ma, $V_3=470$ mv. An oscilloscope display of the results is shown in Fig. 2. The operating speed was measured by applying a step input of the proper amplitude and having a rise time less than 10 nsec. The SUM and CARRY output was observed with a 100-Mc Tektronix scope and the results obtained showed the transient response to be no greater than 10 nsec. It also appears that the SUM output for two inputs is giving the worst transients. These experimental results agree well with the analytical predictions of the circuit, assuming a linearized tunnel-diode I-V characteristic and neglecting any inductances in the circuit. It should be noted that the CARRY output is above ground. A transformer has been used successfully to convert it to a single-ended output. The circuit offers the advantages of simplicity, potential high-speed operation, no steady-state dissipation and low-switching energy.

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Parametric Amplification with a Low-Frequency Pump*

The regenerative, three-frequency parametric amplifier consisting of a varactor, a pump, a signal tank, and an idler tank is well known. The degenerate version of this amplifier results when signal and idler tanks are replaced by a single tank tuned to one-half the pump frequency. This note is to demonstrate the possibility of regenerative signal amplification, or oscillation, with a pump frequency lower than the signal frequency by a specified rational fraction. Leon[1] has shown the possibility of regeneration at an idler frequency greater than the pump frequency, but his findings seem indirectly related to the case discussed here.

Assume a varactor whose displacement q (charge, flux linkage) is a single-valued function of the force v (potential, current), such that

$$q = \sum_{n=1}^{\infty} C_n v^n, \quad (1)$$

the C_n being constants. Let $v=v_p+v_s$, where $v_p=E_p\cos pt$, $v_s=E_s\cos(st+\phi)$. If $C_n\neq 0$, it can be shown that the nth term of (1) is responsible for an average power, delivered by the pumping force v_p and absorbed by the signal force v_s, of

$$W_n = nsC_n(E_p/2)^{n-1}E_s^2/2 \quad (2)$$

provided

$$\begin{cases} \phi = -(\pi/4),\ (3\pi/4) \\ s/p = (n-1)/2. \end{cases} \quad (3)$$

It is therefore possible, given a sufficiently large C_n, to amplify at a signal frequency s with a pump frequency $2s$, $2s/3$, $2s/5$, $2s/7$, etc. Only odd denominators have been chosen; even denominators represent signals harmonically related to the pump,

* Received by the IRE, May 4, 1961.

[1] B. J. Leon, "Exact Analysis of Linear Parametric Amplifiers," presented at URSI Joint Meeting, Washington, D. C., May 3, 1960; submitted to IRE Trans. on Circuit Theory.

and these would ordinarily be obscured by harmonic generation in the varactor. Oscillators powered by a low-frequency pump may be useful as computer storage elements, for in common with parametron oscillators there are two stable choices for the oscillation phase ϕ.

A general theory of the two-frequency varactor can be constructed with the method outlined above. If the single varactor assumed is part of a network in which all other elements are linear, there are only two possible modes of energy transfer from v_p to v_s. The first mode is nonregenerative, *i.e.*, the network can be considered a stable source of current at frequency s. The second is regenerative, and the network presents a negative conductance to v_s at frequency s. One of the negative conductances is represented by the coefficient of E_s^2 in (2). Other useful results of the theory are: 1) two-frequency nonregenerative frequency dividers (subharmonic generators) are not possible, and 2) two-frequency regenerative frequency dividers are not possible, except for division by 2.

With variable-capacitance diodes of the type designed for high-frequency tuning, oscillations have been produced at 9 kc with a 6-kc pump, and at 15 Mc with a 10-Mc pump. The magnitude of C_4 was thus sufficient to demonstrate the effect with the single-tuned circuits available. No oscillations have been obtained using these diodes with the pump at 2/5, or less, of the signal frequency.

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100-Mc Tunnel-Diode Ring Counter*

Ring counters[1] are characterized by the fact that the "one" state is transferred from one stage to the next at each input. In an N-stage ring counter, each stage is required to operate every N counts. It is triggered to the "one" state every N counts but is reset to the "zero" state at the next count. Thus, with this type of arrangement, each stage has a time interval corresponding to $N-1$ counts in which to be reset. It was this fact that motivated the design of the circuit described below.

The logical layout of this ring counter is shown in Fig. 1. It consists of a series of bistable tunnel-diode AND circuits connected in a ring with a small delay between each stage. The input to each stage is a short transient from the input line and a dc input from the preceding AND stage. Thus, stage i cannot be triggered to its "one" state unless stage $i-1$ is already in its "one" state. The reset circuit will reset stage $i-1$ when stage i is triggered. The next input will trigger stage $i+1$ which will reset stage i. Because the AND gates are arranged in a ring, the "one" state will be transferred from one stage to the next at each input. If we have N stages, the ring counter will be in its base state (the first stage in state "one" and all the rest in state "zero") after every N inputs, thus dividing the input count by a scale of N. The delay between successive stages is required to insure that only one count is achieved for each input. An all transistor decade counter based on a similar logical layout has been reported in the literature.[2]

A schematic diagram of a typical stage is shown in Fig. 2. The tunnel diode in series with its load resistor R_1+R_2 is the basic bistable threshold gate which has been discussed in the literature many times.[3] Resistors R_1, R_2, R_4, and R_5 are chosen to give currents I_0, I_1, and I_2 in diode D_i with peak current I_p such that: $I_0+I_1<I_p$; $I_0+I_2<I_p$; $I_0+I_1+I_2>I_p$, where I_2 is the peak value of the transient input current i_2. This defines the basic AND function, and when the preceding stage is in the "high" or "one" state, diode D_i can be triggered by input current i_2. When this stage goes high it saturates transistor T_i, which resets the preceding stage. Capacitors C_2 and C_3 are commutating capacitors to speed the reset. Diode D_2 is required to eliminate reverse current when D_{i-1} is low and D_i is high. Sufficient delay between successive stages is obtained from the finite switching time of each tunnel diode.

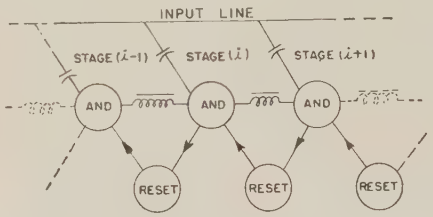
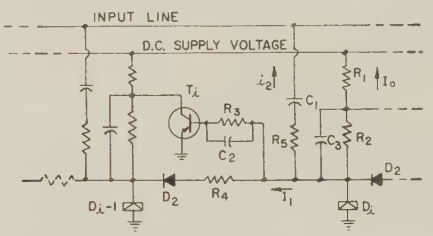


Fig. 1—Logical layout of ring counter.



$R_1=3K$ $C_1=2.2\mu f$ $D_i=5$ ma. germanium tunnel diode
$R_2=270\Omega$ $C_2=100\mu\mu f$
$R_3=820\Omega$ $C_3=56\mu\mu f$ $D_2=$germanium diode supply voltage $=-11$ volts
$R_4=68\Omega$ $T_i=$2N501 transistor
$R_5=270\Omega$

Fig. 2—Schematic diagram of a typical stage in the ring counter.

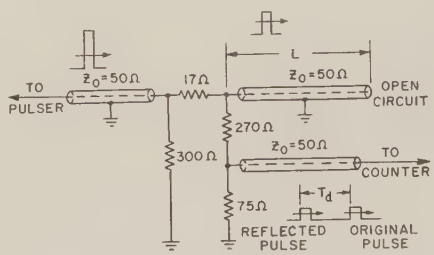


Fig. 3—Circuit used to generate a doublet of narrow pulses.

The input circuit is a 50-ma gallium arsenide diode in series with a 50-ohm resistor, which was chosen to terminate properly the transmission line used for the input cable. Each time the input voltage passes -2.5 volts, the tunnel diode fires and a one-volt step is generated at the input line. This is differentiated by the capacitor C_1 in Fig. 2 and appears as a transient input to all the AND gates. Thus, the counter responds each time the input voltage passes a reference level of -2.5 volts, making the count independent of the input waveshape.

Using the circuit shown in Fig. 3, a doublet of 3-nsec-wide pulses of the same polarity and amplitude was produced. The input pulse was generated by a mercury relay pulse generator. The separation between the original pulse and its reflection is equal to twice the time delay associated with the open-circuited delay line (whose length is adjustable). This doublet was fed into a decade counter using 2N501 transistors; a minimum double pulse resolution time of 10 nsec was observed for reliable counter operation. A smaller double pulse resolution time of 8 nsec was observed using 2N769 transistors for the reset elements, but it is felt that the circuit layout is limiting the minimum resolution time and not the transistors. This same unit was operated successfully using a 100-Mc sine wave input.

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Concerning the Partition Theory and Associated Transform Methods*

In the recent literature there has been considerable discussion of supposedly new transform methods.[1] Wolf, in his discussion, fails to make a distinction between the definition of a transform and methods of application so that his statements and claims are not all valid. His definition of the Laurent-Cauchy transform is given by[2]

$$h_n = \frac{1}{2\pi j}\int_c H(\rho)\rho^{n-1}d\rho \qquad (1)$$

* Received by the IRE, April 27, 1961; revised manuscript received, May 8, 1961.

[1] For a general discussion, see J. Millman and H. Taub, "Pulse and Digital Circuits," McGraw-Hill Book Co., Inc., New York, N. Y., ch. 2; 1956.

[2] "100-Mc solid-state gated counter," *Electronic design*, vol. 8, pp. 58–59; October 12, 1960.

[3] See, for instance, M. H. Lewin, "Negative-resistance elements as digital computer components," *1959 Proc. Eastern Joint Computer Conf.*, no. 16, pp. 15–27; December 1–3, 1959.

* Received by the IRE, February 10, 1961; revised manuscript received, March 13, 1961.

[1] E. V. Bohn and A. A. Wolf, "The equivalence of the Taylor-Cauchy and Laurent-Cauchy transform analysis with conventional methods," Proc. IRE, vol. 49, pp. 358–361; January, 1961.

[2] Y. H. Ku, and A. A. Wolf, "Laurent-Cauchy transforms for analysis of linear systems described by differential-difference and sum equations," Proc. IRE, vol. 48, pp. 923–931; May, 1960.

and

$$H(\rho) = \sum_{n=0}^{\infty} h_n \rho^{-n}. \tag{2}$$

This can be compared with Jury's[3] definition of the Z transform

$$h(nT) = \frac{1}{2\pi j} \int_{\Gamma} H(Z) Z^{n-1} dZ \tag{3}$$

and

$$H(Z) = \sum_{n=0}^{\infty} h(nT) Z^{-n}. \tag{4}$$

That these transforms are identical can be seen by setting $T=1$, $\rho=Z$, and $h(nT)=h_n$. Wolf's reference to sample functions and sequence functions is not relevant. The Z transform cannot distinguish between them. Jury[4] has also commented on the identity of the two transforms in discussing alternate means of deriving some of Wolf's expressions. Wolf makes a comparison with the Laplace and Fourier transforms. That these transforms are different becomes evident when a unit step function is considered. The Fourier transform of a unit step function does not exist. No simple change in notation can convert the Laplace transform, which is $1/s$, into a nonexistent value. There is no justification for the statement that the transform pairs 1, 2 and 3, 4 are generally different. With reference to the Taylor-Cauchy transform, Wolf defines this by[5]

$$W^{(k)}(\lambda) = \sum_{n=0}^{\infty} w_{n,k} \lambda^n \tag{5}$$

and

$$w_{n,k} = \frac{1}{2\pi j} \int_c \frac{W^{(k)}(\lambda) d\lambda}{\lambda^{n+1}}. \tag{6}$$

Using the substitutions $f(t) = W^{(k)}(\lambda)$ and $n! w_{n,k} = a_n$, it becomes evident that the Taylor-Cauchy transform pair represents nothing more than a simple power (Taylor) series and the coefficient of the nth power of t. For example, from Wolf's tables, the Taylor-Cauchy transform of $e^{\alpha t}$ is $\alpha^n/n!$. His statement that the Taylor-Cauchy transform arises from the partition theory is erroneous. The Taylor series (5) and Cauchy's integral formula (6) were both well established before the development of the partition theory.

Wolf's claim that the partition theory represents a new and distinct development is based largely on his discussion of backward recurrence relations. This is only an apparent difficulty which can be eliminated by simply converting the integro-differential equation into a differential equation by means of the substitution

$$D^{-N} y(t) = x(t), \tag{7}$$

where D^{-N} is the highest-order integral operator. The nonlinear differential equation will then have the form

$$u_n = f_n(u_0, u_1, \cdots, u_{n-1}, t) \tag{8}$$

where the notation

$$u_n = u_n(t) = \frac{d^n x(t)}{dt^n} \tag{9}$$

is used. The solution of (8) is to be represented by a power series:

$$x(t) = \sum_{n=0}^{\infty} \frac{a_n}{n!} t^n. \tag{10}$$

It follows from (9) and (10) that

$$a_k = u_k(0). \tag{11}$$

The values $a_0, a_1, \cdots, a_{n-1}$ can be specified as initial conditions. The remaining a_k can be found by differentiating (8) successively with respect to t and then substituting $t=0$. This yields

$$u_{n+1} = \frac{\partial f_n}{\partial u_0} u_1 + \cdots + \frac{\partial f_n}{\partial u_{n-1}} u_n + \frac{\partial f_n}{\partial t} = f_{n+1}(u_0, u_1, \cdots, u_{n-1}, u_n, t) \tag{12}$$

and, for $t=0$,

$$\begin{aligned} a_n &= f_n(a_0, a_1, \cdots, a_{n-1}, 0) \\ a_{n+1} &= f_{n+1}(a_0, a_1, \cdots, a_{n-1}, a_n, 0). \\ &\vdots \end{aligned} \tag{13}$$

There is no difficulty in solving these equations for the a_k's.

To see the equivalence of this conventional method with that of Wolf, it should be noted that he sets

$$\frac{d^n x}{dt^n} = \sum_{k=0}^{\infty} w_k t^k, \tag{14}$$

and obtains recurrence relations for the w_k's. From (10) and (14) the following relation is obtained:

$$w_k = \frac{a_{n+k}}{k!}; \qquad (k \geq 0). \tag{15}$$

Wolf's recurrence relations for the w_k's are obtained by using (15) to eliminate the a_k's from (13). In all the examples discussed the use of the a_k's is more straightforward. In view of the simple relation (15), it is difficult to justify Wolf's statement that the methods are distinctly different. His comments concerning the numerical method used by Dietz[6] is not relevant to this discussion which concerns itself with transforms. Dietz solves the nonlinear integral equation

$$x(t) = \int_0^t g(\tau) h(t-\tau) d\tau - \int_0^t F[x(t)] \cdot h(t-\tau) d\tau, \tag{16}$$

where g, h and F are known functions using numerical procedures. This is very distinct from the transform method which assumes a power-series solution of (16) and obtains recurrence relations for the coefficients.

As a final comment, it should be noted that stochastic inputs are considered by postulating probability-density functions for the coefficients of the power series. The usefulness of this approach is very limited even in the case of linear systems. Wolf states that his methods are principally useful for theoretical and systematic studies. It is difficult to agree with this, in view of the fact that a power-series representation is generally of little use and that all examples cited by him are more readily solved by conventional methods.

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[3] E. Jury, "Sampled-Data Control Systems," John Wiley and Sons, Inc., New York, N. Y.; 1958. See, in particular, Eqs. 1.87, 1.90.

[4] E. Jury, "Laurent-Cauchy transforms for analysis of linear systems described by differential-difference and sum equations," PROC. IRE, vol. 48, pp. 2026–2027; December, 1960.

[5] Y. H. Ku, A. A. Wolf, and J. H. Dietz, "Taylor-Cauchy transforms for analysis of a class of nonlinear systems," PROC. IRE, vol. 48, pp. 912–922; May, 1960.

[6] Y. H. Ku, A. A. Wolf, and J. H. Dietz, "On a systematic approximation to the partition method for analysis of a class of non-linear systems," *Trans. AIEE*, vol. 49, pp. 183–189; July, 1960.

A Theoretical Comparison of Average- and Spot-Noise Figure in Transistor Amplifiers*

It is the purpose of this note to calculate the average-noise figure of a transistor from an assumed functional relationship for the spot-noise figure. From this calculation, the dependence of average-noise figure on noise bandwidth and certain transistor parameters may be obtained and the conditions under which the average-noise figure and spot-noise figure are essentially identical will be evident.

Theory

In Fig. 1, spot-noise figure F_{AO} is plotted as a function of frequency f. In Region I, F_{AO} is assumed to decrease at 3 db per octave increase of frequency. In Region II, F_{AO} is independent of frequency with the value of F_0. In Region III, F_{AO} increases at 6 db per octave. The critical frequency that defines the boundary between Region II and Region III is $(\sqrt{1-\alpha_0}) f_{\alpha b}$. The analysis here will be restricted to $f \leq f_{\alpha b}$ so that the variation

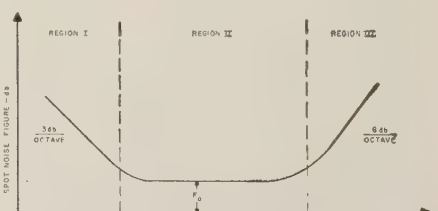


Fig. 1.

* Received by the IRE, March 5, 1961; revision received, March 15, 1961.

shown for Region III holds for the common-emitter, common-base and common-collector connections.

The variation of F_{AO} with f, shown in Fig. 1, defines the functional relationship (1).

$$F_{AO} = \frac{f_{cn}}{f} F_0 + F_0 + \frac{f^2}{(1-\alpha_0) f_{\alpha b}{}^2} F_0, \quad (1)$$

where f is the frequency at which F_{AO} is specified. Now $f_{cn} \ll (\sqrt{1-\alpha_0}) f_{\alpha b}$ so that it is possible to consider two separate cases.

Case 1

For this case

$$F_{AO} = F_0 \left(1 + \frac{f_{cn}}{f}\right). \quad (2)$$

The average noise figure, F_A, is

$$F_A = \frac{\int_{fa}^{fb} G(f) F_{AO}(f) df}{\int_{fa}^{fb} G(f) df}, \quad (3)$$

where the $f_a < f_b$, and $G(f)$ is the available power gain.

$G(f)$ is determined by the transistor and frequency selective networks associated with the particular amplifier circuit being considered. With the $F_{AO}(f)$ necessary to describe transistor spot-noise figure, (3) may be integrated in closed form for only very simple $G(f)$. In particular we may take $G(f)$ as

$$G(f) = \begin{cases} G_0; & f_a \le f \le f_b \\ 0; & f < f_a, f > f_b \end{cases} \quad (4)$$

Substituting (4) into (3) and carrying out the indicated integration gives

$$\frac{F_A}{F_{AO}} = \frac{1}{1 + \frac{f_{cn}}{f_0}} \left[1 + \frac{f_{cn}}{f_0} \frac{f_0}{\Delta f} \ln \left(\frac{2 + \frac{\Delta f}{f_0}}{2 - \frac{\Delta f}{f_0}} \right) \right], \quad (5)$$

where $\Delta f = f_b - f_a$ and

$$f_0 = \frac{f_a + f_b}{2}.$$

Eq. (5) is plotted in Fig. 2. F_A/F_{AO} is shown as a function of $\Delta f/f_0$ with f_{cn}/f_0 as a parameter.

Case 2

$$f_{cn} \ll f \gtrsim (\sqrt{1-\alpha_0}) f_{\alpha b}, \quad f < f_{\alpha b}. \quad (6)$$

For this case we have

$$F_{AO} = F_0 \left(1 + \frac{f^2}{(1-\alpha_0) f_{\alpha b}{}^2}\right). \quad (7)$$

Taking $G(f)$ as in (4) and substituting (4) and (7) into (3) gives

$$\frac{F_A}{F_{AO}} = \frac{1 + \frac{3 f_0{}^2}{(1-\alpha_0) f_{\alpha b}{}^2} \left[1 + \frac{1}{12} \left(\frac{\Delta f}{f_0} \right)^2 \right]}{1 + \frac{3 f_0{}^2}{(1-\alpha_0) f_{\alpha b}{}^2}} \quad (8)$$

where Δf and f_0 are defined as before. Eq. (8) is plotted in Fig. 3. F_A/F_{AO} is plotted as a function of $\Delta f/f_0$ with

$$1 + \frac{3 f_0{}^2}{(1-\alpha_0) f_{\alpha b}{}^2}$$

as a parameter.

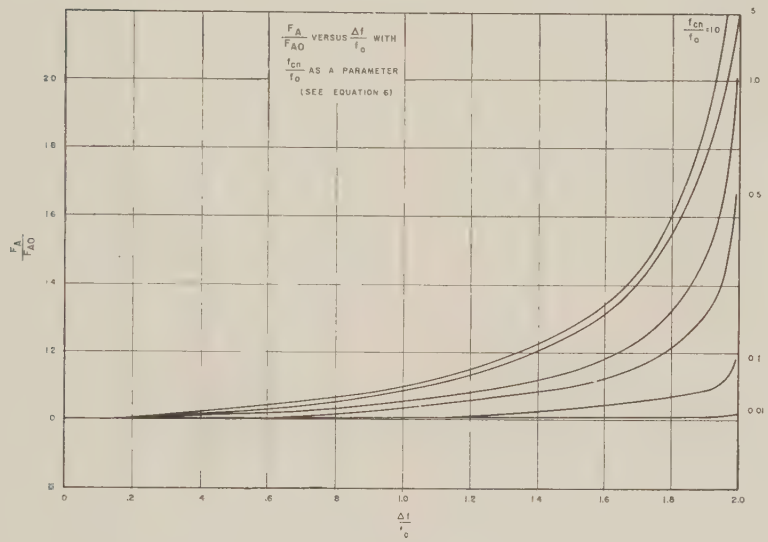


Fig. 2.

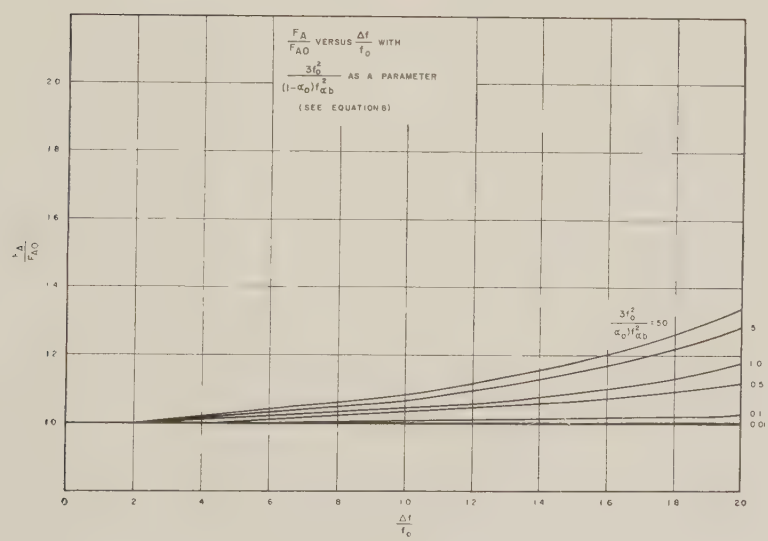


Fig. 3.

Results and Conclusions

By using a particularly simple form for $G(f)$ and approximate expressions for spot-noise figure, equations are derived which relate average-noise figure to spot-noise figure. For both the low-frequency and high-frequency cases the average-noise figure is higher than the spot-noise figure.

For the low-frequency case, F_A will be within 0.5 db of F_{AO} for $\Delta f/f_0 \le 1$ and $f_{cn}/f_0 \le 10$. In the high-frequency case F_A will be within 0.5 db of F_{AO} when $\Delta f/f_0 \le 1.2$ and

$$\frac{3 f_0{}^2}{(1-\alpha_0) f_{\alpha b}{}^2} \le 50.$$

In practice the idealized $G(f)$ of (4) can never be realized. However, since the difference between F_A and F_{AO} is so small for $\Delta f/f_0 \le 0.1$, if a filter is chosen such that the ratio of the effective noise bandwidth to the center frequency is small, the difference between the measured noise figure and the actual spot-noise figure will be small.

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The Calculation of Cutoff Frequencies of Minority-Carrier Transport Factors in Drift Transistors when the Mobilities are not Constant*

The cutoff frequency of minority-carrier transport factor in a drift transistor has been calculated on the assumption that the mobility of an injected minority carrier is independent of the density of impurity in the base region.[1]

Actually, the mobility depends on the density of impurity. In this note, the mobility of holes is assumed as (1) and a cutoff frequency is calculated for a p-n-p drift transistor.

$$\mu_p = \mu_{p_0}\left(\frac{N_d}{N_{d_0}}\right)^{-\nu}, \tag{1}$$

where μ_p is the mobility of holes, μ_{p0} is the mobility at the front of a collector junction, N_{d_0} is the density of donors at the front of the collector junction, and N_d is the density of donors in the base.

For simplicity, the geometries of a transistor are assumed to be one-dimensional.

In the base region, the current is given as

$$j_p = \mu_p\left(qEp - kT\frac{\partial p}{\partial x}\right), \tag{2}$$

where j_p is the density of hole current, q is the electronic charge, E is the intensity of electric field, p is the density of hole, k is Boltzmann's constant, T is the temperature in Kelvin, x is the coordinate; and the distribution of donor density is given by

$$N_d = N_{d_0}e^{-qE/kT(x-a_0)}. \tag{3}$$

The continuity equation of current is

$$\frac{1}{q}\frac{\partial j_p}{\partial x} = -\frac{\partial p}{\partial t} - \frac{1}{\tau_p}\left\{p - p_0 e^{qE/kT(x-a_0)}\right\} \tag{4}$$

where τ_p is the lifetime of holes and p_0 is the hole density in thermal equilibrium.

From the above equations, the equation giving the distribution of holes in the base region is

$$\frac{\partial^2 p}{\partial x^2} - (1-\nu)\frac{\partial p}{\partial x} - \left\{\frac{1}{{L_{p_0}}^2}e^{-(2/f)\nu(x-a_0)} + \left(\frac{2}{f}\right)^2\nu\right\}p - \frac{1}{D_{p0}}e^{-2\nu/f(x-a_0)} = -\frac{p_0}{{L_{p_0}}^2}e^{2/f(1-\nu)(x-a_0)}, \tag{5}$$

where ${L_{p0}}^2$ is $D_{p0}\tau_p$, f is $2kT/qE$, and D_{p0} is $\mu_{p0}kT/q$.

Now, provided that the hole density is divided into three terms as shown in (6), each term satisfies the following boundary conditions:

$$p = p_1 + p_2\frac{q\mu_e}{kT}e^{j\omega t} + p_3 b_1 U_c e^{j\omega t}, \tag{6}$$

where the emitter is located at

$$x = a_0 + a_1 e^{j\omega t} \doteq a_0,$$

the collector at

$$x = b = b_0 + b_1 e^{j\omega t}$$

as shown in Fig. 1 and U_e, and U_c is the amplitude of the sinusoidally-varying junction voltage, the angular frequency of which is ω.

The boundary conditions are as follows:

$$p_1(a_0) = p_2(a_0) = p_0 e^{qV_e/kT}, \tag{7a}$$

$$p_1(b_0) = p_2(b_0) = 0 \tag{7b}$$

$$p_3(a_0) = 0 \tag{8a}$$

$$p_3(b_0) = -p_1'(b_0), \tag{8b}$$

where V_e is the dc voltage of the emitter junction.

If new variables u_1, u_2, u_3, η and ζ, which are defined by (9 a and b), (10 a and b) and (11 a and b), are introduced,

$$p_{1_0} = p_0 e^{2/f(x-a_0)} + \frac{p_0}{{L_{p0}}^2}e^{1/f(1-\nu)(x-a_0)}u_1 \tag{9a}$$

$$\eta = \frac{\nu}{\nu L_{p0}}e^{-\nu/f(x-a_0)}, \tag{9b}$$

$$p_2 = e^{1/f(1-\nu)(x-a_0)}u_2 \tag{10a}$$

$$\zeta = \frac{1}{\nu\lambda}e^{-\nu/f(x-a_0)}, \tag{10b}$$

where

$$\frac{1}{\lambda^2} = \frac{1+j\omega\tau_p}{{L_{p_0}}^2} \tag{11a}$$

$$p_3 = e^{1/f(1-\nu)(x-a_0)}u_3, \tag{11b}$$

then it is easily seen that the equations giving u_1, u_2 and u_3 are equal to the equations of modified Bessel functions as follows:

$$\eta^2\frac{d^2u_1}{d\eta^2} + \eta\frac{du_1}{d\eta} - (\eta^2+n^2)u_1 = 0, \tag{12}$$

where

$$n = 1 + \frac{1}{\nu},$$

$$\zeta^2\frac{d^2u_2}{d\zeta^2} + \zeta\frac{du_2}{d\zeta} - (\zeta^2+n^2)u_2 = 0 \tag{13}$$

$$\zeta^2\frac{d^2u_3}{d\zeta^2} + \zeta\frac{du_3}{d\zeta} - (\zeta^2+n^2)u_3 = 0. \tag{14}$$

Therefore, the hole density is

$$p_1 = p_0 e^{2/f(x-a_0)} + p_0 e^{1/f(1-\nu)(x-a_0)} \times \frac{(e^{qV_e/kT}-1)\left[K_n(\eta_b)I_n(\eta) - I_n(\eta_b)K_n(\eta)\right] + e^{1/f(1+\nu)d}\left[K_n(\eta_a)I_n(\eta) - I_n(\eta_a)K_n(\eta)\right]}{I_n(\eta_a)K_n(\eta_b) - I_n(\eta_b)K_n(\eta_a)} \tag{15}$$

$$p_2 = p_0 e^{qV_e/kT}\frac{K_n(\zeta_b)I_n(\zeta) - I_n(\zeta_b)K_n(\zeta)}{I_n(\zeta_a)K_n(\zeta_b) - I_n(\zeta_b)K_n(\zeta_a)}e^{1/f(1-\nu)(x-a_0)} \tag{16}$$

$$p_3 = p_1'(b_0)e^{1/f(1-\nu)(x-b)}\frac{K_n(\zeta_a)I_n(\zeta) - I_n(\zeta_a)K_n(\zeta)}{I_n(\zeta_a)K_n(\zeta_b) - I_n(\zeta_b)K_n(\zeta_a)}, \tag{17}$$

where I_n and K_n are the first and the second kind of modified Bessel functions of nth order, respectively, the subscripts a and b indicate the values at $x=a$ and b, and d is equal to $b-a$.

From (16) and (17), the ac hole current can be calculated, and the transport factor of hole is calculated from the ratio of the hole current at the collector to the hole current at the emitter.

Then the transport factor β is

$$\beta = \frac{\frac{\nu}{f}e^{d/f(1+\nu)}}{\frac{1}{f}(1+\nu)\left[I_n(\zeta_a)K_n(\zeta_b) - I_n(\zeta_b)K_n(\zeta_a)\right] + \frac{1}{\lambda}\left[I_n'(\zeta_a)K_n(\zeta_b) - I_n(\zeta_b)K_n'(\zeta_a)\right]}. \tag{18}$$

Unfortunately, (18) is very complicated because the variables are complex. Provided that τ_p is infinitely long, I_n and K_n are expanded to the sum of *ber* and *bei*, and the sum of *ker* and *kei*, respectively. Then the numerical calculations are greatly simplified.

For $N_d \geq 10^{16}$, the mobility in germanium varies roughly as $N_d^{-1/3}$.[2] Therefore, ν is chosen to be $\frac{1}{3}$ for a germanium p-n-p drift transistor.

For an example, if d/f is chosen to be 4, which is a typical value for a germanium p-n-p transistor, the numerical calculation of the transport factor indicates that the cutoff frequency f_α is approximately given by

$$f_\alpha \doteq 0.3 f_{\alpha_0}. \tag{19}$$

Here f_{α_0} is the cutoff frequency calculated from the simple theory, in which the mobility is assumed to be constant.

It must be emphasized that the cutoff frequency in a drift transistor is greatly reduced due to the decreased mobility of minority carrier at the neighborhood of the emitter.

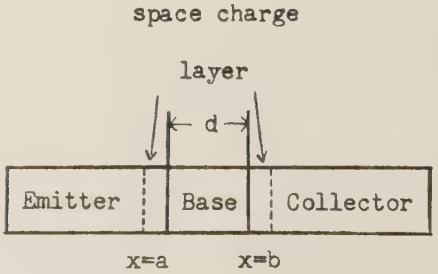


Fig. 1—Geometries of the transistor.

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* Received by the IRE, March 7, 1961.

[1] H. Krömer, "Zur theorie des diffusions- und des drifttransistors, I. II. III," *AEÜ*, vol. 8, pp. 223–228, May; pp. 363–369, August; and pp. 499–504, November, 1954.

[2] L. J. Varnerin, "Stored charge method of transistor base transit time analysis," Proc. IRE, vol. 47, pp. 523–527; April, 1959.

Logarithmic Compression of Binary Numbers*

As probes are launched deeper into interplanetary space, it becomes essential to transmit to earth only information of significance and to strain out unneeded data before it reaches a transmitter. This correspondence describes a device that can accept at its input a large binary number and convert this number into a smaller number related to its logarithm. Specifically, we wish to describe here a converter that accepts an input binary number of up to nineteen digits and compresses this to an eight-bit output binary number. This output, by virtue of its coding, indicates the value of the input to an accuracy of better than ±3 per cent throughout its entire range.

Basically the device gives as its output the significant digits of the input plus other digits that indicate where the decimal point should be placed. For a 19-to-8 bit converter, the four most significant figures of the output number are the total number of digits of the input number minus four. The four least significant figures of the output number are the 2nd, 3rd, 4th, and 5th most significant figures of the input. Specifically if the input binary number is "abcdefghi," where "a" is a "1" then the output number will be "Nbcde" where N equals the total number of digits minus four. In the example N=5 which is the binary 101. Therefore, the output is 101bcde. Specific examples are:

Input	Output
1111111111111111111	11111111
10000000000000000000	11110000
10110011010010110	11110110
00000000011000000	01011000
00000000000000010000	00010000.

For input numbers with four binary digits or less, the device will provide an output number simply equal to the input number.

Fig. 1 is a plot on semilog paper of output vs input for the 19-to-8 bit converter. The square indicated in Fig. 1 is shown in detail in Fig. 2. Any other plot of input values between 2^n and 2^{n+1} where n is greater than 5 will have the same form as Fig. 2. The notation on the right and top of the figure generalizes the plot so that it is applicable for any input number greater than 32. From zero to thirty-two the output is equal to the input.

A block diagram of the device is shown in Fig. 3. The input number is presented in serial form with the most significant digits presented first. A data pulse in coincidence with a clock pulse is a "one." A clock pulse alone is "zero."

Five clock pulses after the first *data* pulse has been received, a "one" has propagated through the shift register and into the switching flip-flop. This binary changes state and stops generation of switching pulses by its action on the shifting pulse gate. This stops the shift register from any further shifting action, leaving all information in the register intact.

When the switching flip-flop changes state, it also puts the counter gate into a condition to pass clock pulses, including the clock pulse that activated it. Therefore, the total number of digits less four are counted by the counter.

When the conversion is completed the 2nd, 3rd, 4th, and 5th most significant figures of the input are in the shift register, while the counter contains the number of input digits less four.

Other similar schemes can be used to obtain different accuracies or different ranges. The larger the shift register, the more closely the actual value of the input number is known. The larger the counter, the greater the range of input numbers that can be converted.

It is also possible to accept counts rather than a binary number at the input of a different sort of device and to present an output identical to that described above. This device will be described in a later communication.

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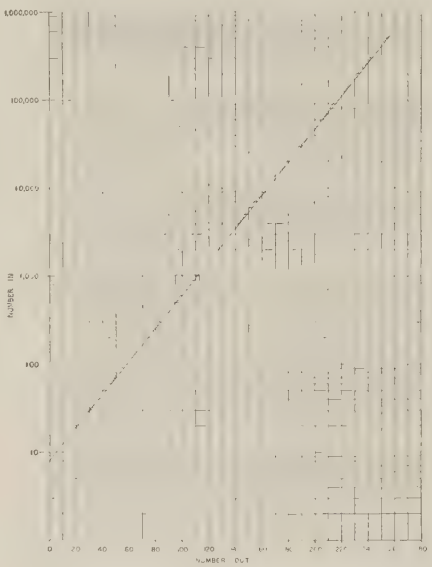


Fig. 1—Output vs input for 19-to-8 bit logarithmic converter.

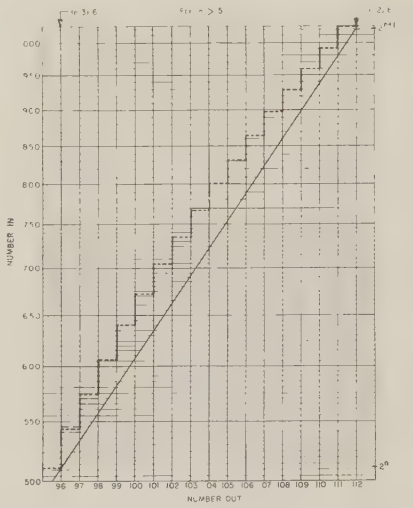


Fig. 2—Detail of square shown in Fig. 1. This figure can be generalized by use of the notation on the right and top of the figure.

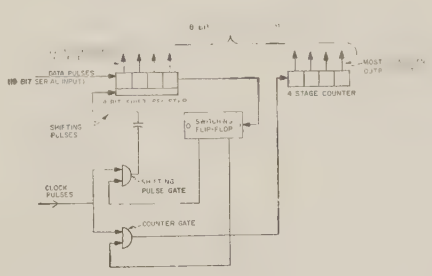


Fig. 3—Converter block diagram. At the beginning of a cycle all flip-flops are in their zero condition.

* Received by the IRE, February 1, 1961; revision received, March 15, 1961.

Converter Efficiency and Power Output of a Tunnel-Diode Relaxation Oscillator*

This brief note is to consider the efficiency and power output of a tunnel diode operated as a dc to ac converter. Such a converter is especially suitable for use in conjunction with thermoelectric generators because both are low impedance devices and the voltage required to bias the tunnel diode into the negative resistance region is obtainable from single-cell thermoelectric generators like lead telluride. A tunnel diode has a characteristic negative resistance region[1,2] as shown in Fig. 1(a). For the purpose of analysis, the characteristic in and near the negative resistance region is approximately represented by

$$i = -ae + be^3, \tag{1}$$

where i and v are the incremental values of current and voltage with regard to their respective quiescent values I_0 and V_0, that is, $i=I-I_0$ and $V=V-V_0$. To obtain a symmetrical ac waveform, we assume that $V_0=(V_1+V_2)/2$ and $I=(I_1+I_2)/2$, the meaning of I_1, I_2, V_1 and V_2 being self-explanatory from Fig. 1(a). By setting $di/de=0$ and

$$i = -(I_1 - I_2)/2 \text{ at } V = (V_2 - V_1)/2,$$

we obtain

$$a = \frac{3}{2}\frac{I_1 - I_2}{V_2 - V_1} \text{ and } b = 2\frac{I_1 - I_2}{(V_2 - V_1)^3}. \tag{2}$$

Suppose that we connect the tunnel diode to a *G-L-C* circuit as shown in Fig. 2(a). Thus, we have

$$i = -(i_L + i_C + i_G) = -\frac{1}{L}\int edt - C\frac{de}{dt} - Ge = -ae + be^3 \tag{3}$$

* Received by the IRE, March 13, 1961.

[1] L. Esaki, "New phenomenon in narrow germanium p-n junctions," *Phys. Rev.*, vol. 109, pp. 603–604; January, 1958.
[2] I. A. Lesk, N. Holonyak, U. S. Davidsohn, and M. W. Aarms, "Germanium and silicon tunnel diodes—design, operation and application," 1959 IRE WESCON Convention Record, pt. 3, pp. 9–31.

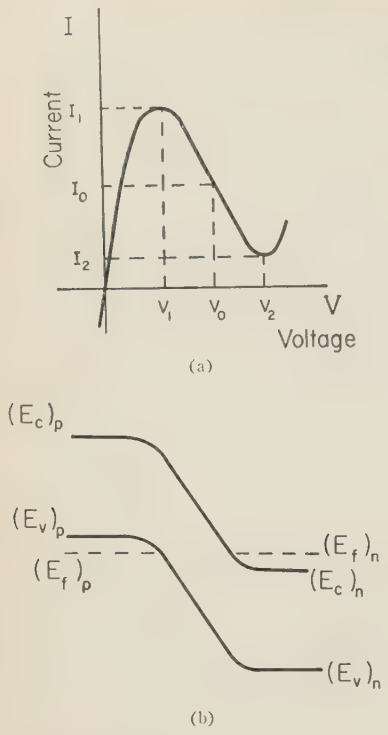


Fig. 1—(a) Tunnel diode current-voltage characteristic. (b) Tunnel diode energy-band diagram.

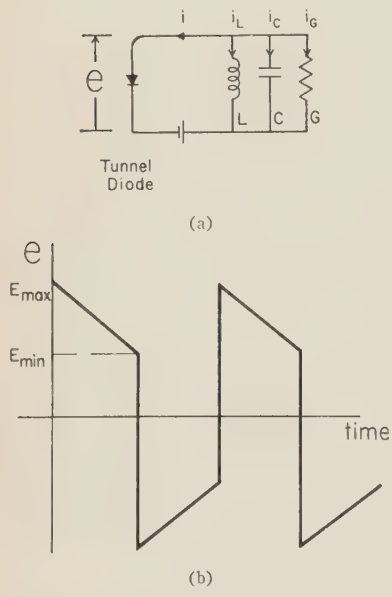


Fig. 2—(a) Tunnel diode converter circuit. (b) Relaxation oscillation waveform with $\alpha \gg 1$ in (3).

or

$$\frac{d^2e}{dt^2} - \alpha(1 - \beta e^2)\omega_0 \frac{de}{dt} + \omega_0^2 e = 0, \qquad (3)$$

where

$$\omega_0 = (LC)^{-1/2}, \qquad \alpha = (a - G)/\omega_0$$

and

$$\beta = 3b/(a - G).$$

The solution of (3), known as the Van der Pol equation, has been discussed extensively in the literature.[3] For $\alpha \gg 1$, the solution has a waveform shown in Fig. 1(b) and is known as relaxation oscillation. The voltage decreases almost linearly from $E_{max} = 2/\beta^{1/2}$ to $E_{min} = 1/\beta^{1/2}$ and then suddenly changes to $-E_{max}$. Assuming a linear decrease from E_{max} to E_{min}, we find the rms value of the voltage, $E_{rms} = (7/3)^{1/2} E_{min}$ or the ac power output

$$P_{ac} = E_{rms}^2 G = \frac{7}{9} \frac{(a - G)}{b} G. \qquad (4)$$

For a maximum P_{ac}, $G = \frac{1}{2}a$. Thus

$$(P_{ac})_{max} = \frac{7}{36} \frac{a^2}{b} = \frac{7}{32} (I_1 - I_2)(V_2 - V_1). \qquad (5)$$

The dc input into the circuit is

$$P_{dc} = I_0 V_0 = \tfrac{1}{4}(I_1 + I_2)(V_1 + V_2), \qquad (6)$$

and therefore, the efficiency of conversion is

$$\eta = \frac{7}{8} \frac{(I_1 - I_2)(V_2 - V_1)}{(I_1 + I_2)(V_2 + V_1)}. \qquad (7)$$

A typical germanium tunnel diode has peak point voltage and current, $V_1 = 60$ mv and $I_1 = 1$ ma, and valley point voltage and current, $V_2 = 300$ mv and $I_2 = 0.1$ ma. This will give us a conversion efficiency of 48 per cent. For high conversion efficiency, we want to make I_1/I_2 and V_2/V_1 as large as possible. For commercial tunnel diodes, the ratio peak to valley current may vary from 5:1 to 40:1. The current near the valley region is at present not well understood. There is a possible suggestion that impurity states in the forbidden band might contribute extra tunneling current in addition to the normal tunneling and diffusion currents. A reduction of this extra current certainly will help the conversion efficiency. The peak and valley point voltages are determined by the amount of doping used in both sides of the junction. Here again, the valley point voltage may be shifted to larger values due to the existence of the extra tunneling current. Assuming no extra tunneling current, it is clear from Fig. 1(b) that $V_2 = (E_f)_n - (E_c)_n + (E_v)_p - (E_f)_p$. If the n and p sides are equally degenerate, it is expected that $V_1 = (E_f)_n - (E_c)_n = (E_v)_p - (E_f)_p$ and $(V_2 - V_1)/(V_2 + V_1) = \frac{1}{3}$. For $I_1/I_2 = 10$, this will give us a conversion efficiency at 23 per cent. For power conversion, it may be necessary to connect several tunnel diodes in parallel to give the needed current. A further reduction of efficiency may result if the diodes do not have identical characteristics. It should also be pointed out that (1) is an oversimplified representation of the diode characteristic. For accurate representation, even terms, which will produce unsymmetrical waveform, and additional odd terms, may be needed. However, we find in our laboratory that the experimental value of E_{max} agrees well with the theoretical value based upon (1). Apparently, (1) is a fairly good approximation.

The author wishes to thank F. Gevert for a discussion of the experimental work which lends support to the present analysis.

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[3] See, for example, W. J. Cunningham, "Introduction to Nonlinear Analysis," McGraw-Hill Book Co., New York, N. Y., chap. 6; 1958.

Vertical Incidence Doppler Ionogram*

The measurements of vertical movements of the E layer of the ionosphere described by Ogawa, Ando and Yoshida[1] are closely similar to those made by the author and published in a series of papers.[2–4] The technique used in the author's measurements of phase path changes differs somewhat from those described[1] and has the advantages that both the sense and magnitude of phase path changes can easily be determined. Also, the phase of echoes returned from the E layer is often irregular in its time time variation due to irregularities in the layer itself.[2] The technique used by the author was derived from suggestions in papers by Hafstad and Tuve[5] and Ranzi.[6]

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Authors' Comment[7]

It seems the essential difference between Findlay's method and ours is that the change in the phase path ΔP is observed, or the time derivative of the phase path dP/dt is observed. Therefore, the former has the advantage in the case of the slow and large movement of the ionosphere and the latter has in the case of the rapid and small movement. When the former and the latter have the errors of $\delta(\Delta P)$ and $\delta(dP/dt)$, respectively, and if the change in the phase path is $\delta(\Delta P)$ in the time interval of more than $\delta(\Delta P)/\delta(dP/dt)$, it cannot be observed by the latter; on the other hand, if the speed of the change of the phase path is $\delta(dP/dt)$ in the time interval of less than $\delta(\Delta P)/\delta(dP/dt)$ it cannot be observed by the former.

The sense of the change would be easily observed in our method if a 90° phase shifter for the reference signal and a phase sensitive detector would be added to our system, which was pointed out in our note.

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* Received by the IRE, March 20, 1961.

[1] T. Ogawa, S. Ando, and A. Yoshida, "Vertical incident Doppler ionogram," Proc. IRE, vol. 49, p. 643; March, 1961.

[2] J. W. Findlay, "The phase and group paths of radio waves returned from region E of the ionosphere," *J. Atmos. and Terr. Phys.*, vol. 1, no. 5/6, p. 353; 1951.

[3] J. W. Findlay, "An investigation of sudden radio frequency near 2 Mc/sec," *J. Atmos and Terr. Phys.*, vol. 1, no. 5/6, p. 367; 1951.

[4] J. W. Findlay, "Moving clouds of ionization in region E of the ionosphere," *J. Atmos. and Terr. Phys.*, vol. 3, no. 2, p. 73; 1953.

[5] L. R. Hafstad and M. A. Tuve, "An echo interference method for the study of radio paths," Proc. IRE, vol, 17, pp. 1786–1792; October, 1929.

[6] I. Ranzi, *Nature*, vol. 132, p. 14; July, 1933.

[7] Received by the IRE, April 24, 1961.

On Scattering Matrices Normalized to Complex Port Numbers*

This paper is concerned with the following practical question. Suppose a linear, time-invariant $2n$-terminal network N (Fig. 1) is excited at its n ports by n generators $E_1, E_2, \cdots, E_n$, with prescribed internal impedances $z_1(j\omega), z_2(j\omega), \cdots, z_n(j\omega)$, respectively. How does one decide upon an appropriate electrical description for N when interest centers mainly on the distribution of average ac power throughout the structure? More specifically, if the z's are not real and positive but are complex over the frequency band under consideration, is it still possible to describe N in terms of a "normalized" $n\times n$ scattering matrix, $S=(s_{kl})$, which is unitary when N is lossless and such that under matched terminations (Fig. 2) the transducer power gain, $G_{kl}(\omega^2)$, from port k to port l is measured by[1]

$$G_{kl}(\omega^2) = |s_{lk}(j\omega)|^2? \tag{1}$$

Interestingly enough, the answer turns out to be in the affirmative if the z's have positive real parts over the frequency range of interest. Before embarking on the proof we introduce some matrix notation.

Let A be an arbitrary matrix. Then A' and $\overline{A}'=A^*$ denote the transpose and the complex conjugate transpose (also called the adjoint) of A, respectively. Column vectors are written $\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{x}$ etc., and in the alternative form $\boldsymbol{x}=(x_1, x_2, \cdots, x_n)'$ whenever it is desirable to exhibit the components explicitly. The matrices 1_n and 0_n are, in the same order, the $n\times n$ identity matrix and the $n\times n$ zero matrix. For an hermetian matrix $A=A^*$, $A\geq 0_n$ means that A is the matrix of a non-negative quadratic form.

Refer to Fig. 1 and assume that the internal impedances $z_1(j\omega), z_2(j\omega), \cdots, z_n(j\omega)$ have positive real parts over the frequency band W; *i.e.*,

$$\text{Real } z_k(j\omega) = r_k(\omega) > 0, \qquad \omega\epsilon W, \quad (k = 1, 2, \cdots, n). \tag{2}$$

The normalized incident and reflected wave amplitudes a_k and b_k impinging on the kth port of N are defined as linear combinations of the associated port voltages and currents according to the scheme:

$$2\sqrt{r_k}\, a_k = V_k + z_k I_k, \tag{3}$$

$$2\sqrt{r_k}\, b_k = V_k - \bar{z}_k I_k, \quad (k = 1\ 2, \cdots, n). \tag{4}$$

All square roots have been chosen positive. The $n\times n$ scattering matrix $S(j\omega)$ of N, normalized with respect to the n impedances $z_1(j\omega), z_2(j\omega), \cdots, z_n(j\omega)$, is defined by means of the linear matrix equation

$$\boldsymbol{b} = S\boldsymbol{a}, \tag{5}$$

where $\boldsymbol{a}=(a_1, a_2, \cdots, a_n)'$ and $\boldsymbol{b}=(b_1, b_2, \cdots, b_n)'$. A more explicit expression for $S(j\omega)$ appears later.

* Received by the IRE, February 18, 1961. Revised manuscript received, March 8, 1961.

[1] H. J. Carlin, "An Introduction to the Use of the Scattering Matrix in Network Theory," Microwave Res. Inst., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., Rept. R-366-54, PIB-300; 1954.

$$\underline{a} = (a_1, a_2, \cdots, a_n)'; \quad \underline{b} = (b_1, b_2, \cdots, b_n)'$$

$$\underline{V} = (V_1, V_2, \cdots, V_n)'; \quad \underline{I} = (I_1, I_2, \cdots, I_n)'$$

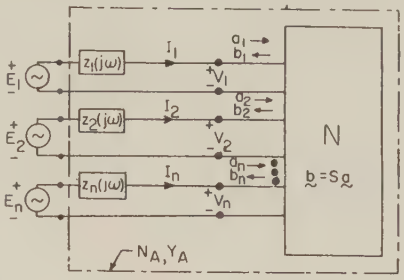
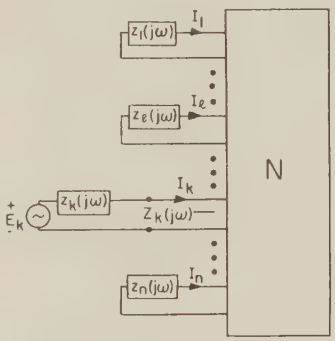


Fig. 1—Schematic of a linear, time-invariant $2n$-terminal network excited at its n ports by n generators $E_1, E_2, \cdots, E_n$ with respective internal impedance $z_1, z_2, \cdots, z_n$.



$$z_m(j\omega) = r_m(\omega) + j\, x_m(\omega),$$

$$(m = 1, 2, \cdots, n).$$

$$G_{k\ell}(\omega^2) = \frac{r_\ell |I_\ell|^2}{\dfrac{|E_k|^2}{4 r_k}}, \quad \ell \neq k.$$

Fig. 2—Schematic illustrating the meaning of the transducer power gain $G_{kl}(\omega^2)$ from port k to port l under matched terminations.

Let P_k equal the average power entering N through port k, *i.e.*, $P_k=\text{Real}\ (\overline{V}_k I_k)$. Using (3) and (4), an easy calculation yields

$$P_k = |a_k|^2 - |b_k|^2, \quad (k = 1, 2, \cdots, n). \tag{6}$$

Thus, P_{AV}, the total average power absorbed by N, is given by

$$P_{AV} = \sum_{k=1}^{n} P_k = \sum_{k=1}^{n} |a_k|^2 - \sum_{k=1}^{n} |b_k|^2 = \boldsymbol{a}^*\boldsymbol{a} - \boldsymbol{b}^*\boldsymbol{b}, \tag{7}$$

which, with the aid of (5), transforms into

$$P_{AV} = \boldsymbol{a}^*(1_n - S^*S)\boldsymbol{a}. \tag{8}$$

Consequently, if N is lossless over W, $P_{AV}(\omega^2)=0$, $\omega\epsilon W$, for any $\boldsymbol{a}$, and this, in turn implies that

$$1_n - S^*(j\omega)S(j\omega) = 0_n; \tag{9}$$

i.e., $S(j\omega)$ is unitary for $\omega\epsilon W$. Again, if N is dissipative, $P_{AV}(\omega^2)\geq 0$ for all $\boldsymbol{a}$, and so

$$1_n - S^*(j\omega)S(j\omega) \geq 0_n, \tag{10}$$

$\omega\epsilon W$. Thus the normalization procedure subsumed in (3) and (4) has succeeded in preserving two of the most important properties possessed by a scattering matrix normalized to real positive port numbers.[1]

Let all ports of N except the kth port be closed on their respective normalization impedances and suppose that port k is driven as shown in Fig. 2. Then.

$$V_l = -z_l I_l, \qquad l \neq k. \tag{11}$$

According to (3), (11) is equivalent to

$$a_l = 0, \qquad l \neq k. \tag{12}$$

Hence, from (5),

$$b_l = s_{lk}(j\omega)a_k, \qquad (l = 1, 2, \cdots, n), = s_{lk}(j\omega)\frac{E_k}{2\sqrt{r_k(j\omega)}}, \tag{13}$$

since, as is obvious from Fig. 2, $E_k=V_k+z_kI_k$. Eq. (11) coupled with (4) yields

$$b_l = -\sqrt{r_l(j\omega)}\, I_l, \qquad l \neq k, \tag{14}$$

and therefore [see (13)]

$$|s_{lk}(j\omega)|^2 = \frac{r_l(j\omega)|I_l|^2}{\dfrac{|E_k|^2}{4r_k(j\omega)}} = G_{kl}(\omega^2), \qquad l \neq k, \tag{15}$$

the transducer power gain from port k to port l. To determine $s_{kk}(j\omega)$, let $Z_k(j\omega)$ represent the impedance seen looking into port k under matched terminations (Fig. 2). Then $V_k=Z_kI_k$ and the division of (4) by (3) yields, with the help of (13),

$$\frac{b_k}{a_k} = s_{kk}(j\omega) = \frac{V_k - \bar{z}_k I_k}{V_k + z_k I_k} = \frac{Z_k - \bar{z}_k}{Z_k + z_k}. \tag{16}$$

It is possible to express S in terms of $Y_A(j\omega)$, the admittance matrix of N_A, the "augmented" n port associated with N. From Fig. 1,

$$\begin{aligned} \boldsymbol{I} &= Y_A\boldsymbol{E} = Y_A(\boldsymbol{V} + Z\boldsymbol{I}). \\ \therefore \boldsymbol{V} - \overline{Z}\boldsymbol{I} &= (\boldsymbol{V} + Z\boldsymbol{I}) - (Z + \overline{Z})\boldsymbol{I} \\ &= \boldsymbol{V} + Z\boldsymbol{I} - 2R\boldsymbol{I} \\ &= (1_n - 2RY_A)(\boldsymbol{V} + Z\boldsymbol{I}). \end{aligned} \tag{17}$$

Hence,

$$\begin{aligned} 2R^{1/2}\boldsymbol{b} &= 2(1_n - 2RY_A)R^{1/2}\boldsymbol{a}. \\ \therefore\ S &= 1_n - 2R^{1/2}Y_AR^{1/2}. \end{aligned} \tag{18}$$

Under our assumptions, Y_A certainly exists if N is passive. Now if N is reciprocal, Y_A is symmetric ($Y_A=Y_A'$) and therefore S is also symmetric since $R^{1/2}$ is diagonal. For a more complete discussion the reader should consult Youla.[2]

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[2] D. C. Youla, "Solution to the Problem of Complex Normalization," Microwave Res. Inst., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y. Memo. 48, Contract AF-30(602)-2213; January, 1961.

TM Modes in Parallelogramic Waveguides*

A paper by Swift and Higgins[1] contains comments on a previous article of Malvano,[2] to the effect that a waveguide of parallelogramic cross section cannot support a TM mode free of nodal lines. This implies the possibility that rapid attenuation of the TM_{11} mode in rectangular guide occurs when the guide is deformed into one of parallelogramic cross section and hence we have the characteristic of a mode filter. However, the implication that a slight deformation of a rectangular guide would suppress the mode TM_{11} conflicts with intuition, because it seems that a mode free of nodal lines, as shown in Fig. 1, could exist in a parallelogramic guide.

In order to resolve this argument, the following experiment has been performed. A waveguide section one meter long having a side ratio $\sqrt{2}/2$ (as considered by Malvano) was fabricated with flexible joints so that parallelogramic cross sections of varying angle could be easily obtained. At both ends of this waveguide section, a short-circuiting brass plate was located, properly clamped, so that a good contact was assured along the edge of the guide. At the center of the figure of each shorting plate (*i.e.*, at the intersection of the diagonals of the waveguide cross section), an axial probe was placed. One of the probes was acting as an exciter, and the other as a pick-up for the radiation transmitted along the waveguide. The choice of the axial probe was suggested by the geometry of the expected field, and in consideration of the fact that for a rectangular waveguide the TM_{11} mode is efficiently excited by such a probe. The waveguide cutoff was obtained by measuring the variation of insertion loss vs frequency for constant angle of parallelogramic cross section.

In order to establish that there is a smooth transition from the TM_{11} mode of rectangular guide to the modal pattern depicted in the sketch, measurements of field intensity along the inner surface of the guide around a cross section were made by probing the field with a small electric probe. The field intensity measurements have shown that a TM mode free of nodal lines does exist in guides of parallelogramic cross section.

The experimental data of f_c as a function of α for the fabricated guide are shown in Fig. 2. In the same figure is shown the plot of the equation

$$f_c = \frac{b^2 \sin^2 \alpha + a^2}{\sqrt{\epsilon\mu}\, 2ab \sin \alpha},$$

obtained by considering the TM_{11} cutoff frequency of a rectangular guide having the same base but a height equivalent to the projection of the inclined side of the parallelogramic guide. One can observe that the difference between this curve and the experimental value is less than three per cent for angles from 90° to 30°.

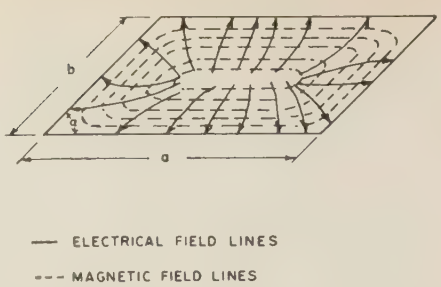


Fig. 1—Conjectured field pattern of dominant mode in a parallelogramic guide; solid lines represent electric field lines, and dashed lines magnetic field lines.

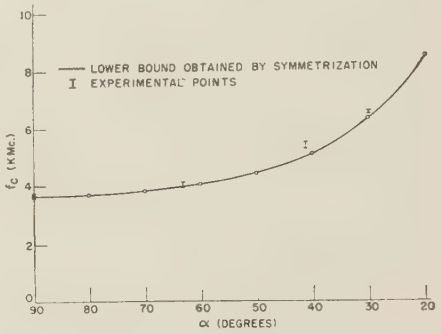


Fig. 2—Cutoff frequency of dominant TM mode vs acute angle of a parallelogramic guide.

This surprisingly good approximation might be interpreted in terms of the geometric operation called "symmetrization," which has been applied by Pólya[3] to the analogous case of vibrating membranes clamped at the edges. Properly applying this operation to a rectangular membrane, one can determine upper and lower bounds for the principal frequency of vibration in a rhombic membrane, and also establish the lower bound for the case of a general parallelogramic membrane. In his article,[3] Pólya demonstrates that symmetrization of a plane figure about a line always decreases the principal frequency of vibration. Hence, symmetrization of a parallelogramic membrane about a line parallel to its vertical will result in a rectangular membrane having a principal frequency which determines a lower bound for the cutoff frequency of the parallelogram. The formula for f_c shown above coincides with the equation defining the lower bound obtained by symmetrization. Unfortunately, there is no line about which a general parallelogram itself (excepting a rhombus and rectangle) is symmetric; hence, one cannot establish an upper bound by this technique.

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* Received by the IRE, March 3, 1961; revised manuscript received, March 16, 1961.

[1] W. B. Swift and T. H. Higgins, "Electromagnetic propagation through waveguides of rhombic cross-section," *Proc. NEC*, vol. 8, pp. 273–284; October, 1952.

[2] R. Malvano, "Guida d'onda metallica a sezione parallelogramma," *Nuova Cimento*, series 9, vol. 6, pp. 265–273; July, 1949.

[3] G. Pólya, "Torsional rigidity, principal frequency, electrostatic capacity and symmetrization," *Quart. Appl. Math.*, vol. 6, pp. 267–277; April, 1948.

A Nondirectional Ferrite Rod Antenna Arrangement Suitable for AM Radios*

This note describes a ferrite rod antenna arrangement suitable for a standard AM radio, and the method by which it is possible to obtain an essentially nondirectional polar pattern. The arrangement is schematically illustrated in Fig. 1, and consists of two mutually-perpendicular, separately-tuned, conventional ferrite rod antennas. By quadrature addition of the two separate antenna signals thus obtained, a perfectly circular polar pattern may be produced. However, even if the addition is not entirely in quadrature, substantial advantages are gained—as is shown by the following development.

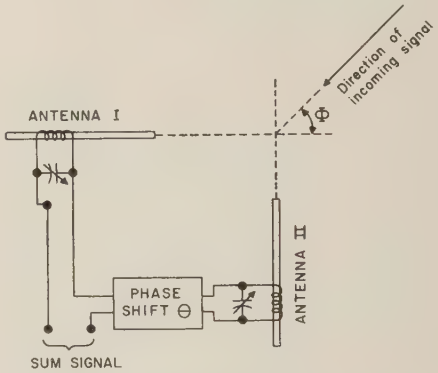


Fig. 1—Nondirectional ferrite rod antenna arrangement.

If the two antennas are identically constructed and tuned to the same frequency, their output signals may be expressed as:

$$S_1(t) = A_0 \cos \omega t \sin \Phi, \tag{1}$$

$$S_2(t) = A_0 \cos \omega t \cos \Phi, \tag{2}$$

where A_0 is a suitable amplitude factor, ω is the angular speed of the received signal, and Φ is the angle between the axis of the ferrite rod of Antenna I and the direction of the incoming signal. If the output from Antenna II is subjected to a phase shift θ and then added to the signal from Antenna I, the amplitude of the resulting sum signal may be obtained by vectorial addition, yielding

$$A_r = A_0 \sqrt{1 + \sin 2\Phi \cos \theta}, \tag{3}$$

which is an expression for the polar pattern of the antenna arrangement shown in Fig. 1.

From (3), it is seen that the ratio between maximum and minimum amplitudes, as obtained when rotating the whole antenna arrangement, can be expressed as

$$R = \sqrt{\frac{1 + |\cos \theta|}{1 - |\cos \theta|}}. \tag{4}$$

From (4) it is found that even if θ deviates fom 90° by as much as ±35°, the resulting polar pattern is still circular within ±3 db.

* Received by the IRE, March 3, 1961; revised manuscript received, March 16, 1961.

This implies that no great accuracy is required in the phase-shifting network, and also that it is not imperative to have perfect tracking between the two tuned circuits when they are tuned over a frequency band.

There are many ways in which to affect the required 90° phase shift. One particularly attractive possibility appears to be that of critically coupling the one antenna to the other. It is well known that in this case the voltage induced in one of the tuned circuits will couple across to the other one with a 90° shift in phase. Consequently, by using the output from either one of the two tuned circuits thus coupled, the effect of a perfectly circular polar pattern should result.

In an experiment performed, critical coupling was established through mutual inductance, and simply by placing the two individual antennas in close proximity to one another. The signal strength across the tuned circuit of Antenna II was then recorded as the whole antenna arrangement was rotated 360° in a plane perpendicular to the direction of polarization of the received signal. Fig. 2 shows the resulting polar patterns as they were obtained at three different frequencies in the AM band. It is to be emphasized that no adjustment in the coupling between the ferrite rod antennas was made during the experiment.

When, as above, the 90° phase shift is established by means of critical coupling, it is to be expected that the effective bandpass characteristics of the antenna arrangement will change with direction of the incoming signal. In Fig. 3 are shown the selectivity curves obtained with the direction of the incoming signal either perpendicular or parallel to the axis of Antenna II. These curves indicate, however, that the changes are not large enough to affect materially the overall selectivity characteristics of a conventional AM radio.

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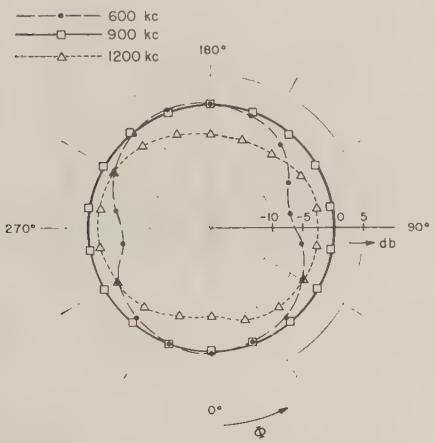


Fig. 2—Experimentally-obtained polar patterns.

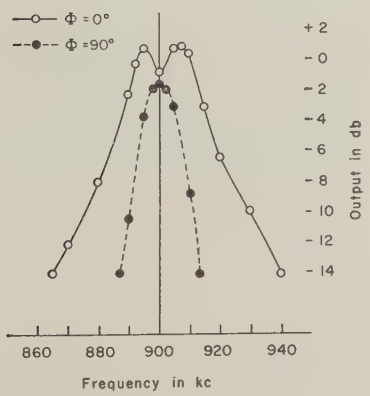


Fig. 3—Selectivity of antenna arrangement for different directions of incoming signal.

"Noisemanship"—The Art of Measuring Noise Figures Nearly Independent of Device Performance*

Almost everyone who has measured the noise performance of a sensitive amplifier or converter has found it possible to read noise-figure values considerably lower or higher than expected. The more exacting experimenters among us have refined their measurement techniques to eliminate such ambiguities and can even obtain accurate noise-figure values for the new, exotic, negative-resistance devices such as parametric amplifiers, masers, and tunnel diode amplifiers and converters. However, as yet, only a few astute practitioners have recognized the tremendous practical value of being able to read noise-figure values much lower or higher than actual. For example, when evaluating their own devices, they can manage to read unusually low noise figures by following certain experimental procedures. (Do not be anxious about their results being much better than theoretical, since they can usually postulate some plausible explanation such as space-charge smoothing.) Conversely, when evaluating their competitors' devices, they can just as readily manage to read exceptionally high noise figures. (Here, however, they usually do the gentlemanly thing and make the magnitude of the noise figures inversely proportional to their competitors' abilities.) To encourage the practice of noisemanship, and thereby bring these very effective practical advantages to all those interested in advancing the state of the art of low-noise devices, we have compiled a partial list of the correct experimental procedures to follow in these two cases.

Case I—Procedures to Be Followed for High-Noise-Figure Readings

1) Use a post-receiver that is very nearly saturated; this makes the output indication almost completely independent of the device under test. By varying the degree of saturation, this one technique alone can lead to almost any desired high noise-figure value.
2) Place a grid-dip meter or sweep generator near the receiver IF amplifier; this is not as effective as procedure 1), but less readily detected by unfriendly observers.
3) Use an argon-discharge noise tube, but use a calibration chart for a neon tube. Since the argon tube has about 3-db less effective output-noise power, an error of 3 db in your favor is easily obtainable. This technique is especially useful if skilled unfriendly observers are present, since the discharge is not visible in any commercial noise generator (because the noise lamp is always located inside a waveguide or coaxial structure) and, therefore, they cannot tell the type of discharge present from its characteristic color.
4) Use a noise generator having the biggest possible difference in source impedance at the two reference noise levels (assuming that a *Y*-factor measurement is made, which is generally true above a few hundred megacycles where noise diodes are no longer useful). This causes a difference in the gain of the device for the two reference conditions. Here, however, one must be careful that the gain decreases when the higher reference temperature is connected. One should also allow sufficient time between the two reference readings so that the output indicator drifts well down scale before the high temperature reference is connected. The use of a badly mismatched noise generator may also cause an unstable device to break into oscillation; if so, an immediate victory is scored.
5) Orient the noise generator for maximum TV, FM, and police radio pickup.
6) Assume that the device has at least three equal spurious responses and, therefore, add 5 db to the measured-noise-figure value. This gives you a knowledgeable air and usually impresses those present.

There are an unusually large number of these procedures, which are too numerous to list here. However, by the use of the few techniques listed above, one can readily pin the noise-figure indicator on the infinite end of the scale. For those pessimists who have only lately entered the low-noise arena, these techniques are guaranteed to lead to immediate positive results.

Case II—Procedures to Be Followed for Low-Noise-Figure Readings

1) Undo procedures 1), 2) and 5) above.
2) Reverse procedures 3) and 4) above.
3) Neglect any spurious responses and quote only the radio-astronomy noise figure.
4) If the observers are aware of the above procedures, place a carefully measured 100-db pad between the noise generator and the device under test. This will eliminate the gain variations caused by noise-generator mismatch, but when 100 db is sub-

* Received by the IRE, March 27, 1961.

tracted from the over-all reading, a low-noise figure is sure to result. An alternate procedure is to use a post-receiver with a 100-db noise figure and then carefully subtract its noise contribution.

Again there are too many of these procedures to list here, but if only the few above are followed, noise figures below 0 db can easily be obtained. This may be a little embarrassing in the presence of theoretically inclined antagonists, but again one can postulate some elaborate thermodynamic mechanism as the probable cause. (If you are anxious about such a procedure, use only one or two of the above procedures, and the noise figure indicator will rest just slightly above the 0-db mark, which is much more readily explained.) For those adventurers who have only lately entered the low-noise arena, these techniques guarantee an immediate entrance into the innermost ring.

In conclusion, techniques have been listed to encourage the rapid growth of noisemanship. Here, however, we think it appropriate to paraphrase Oscar Wilde, who noted that people only like to give advice they will not follow themselves, and with his characteristic wit denoted such advice as the depth of generosity.

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A Liquid-Helium-Cooled Coaxial Termination*

A 50-ohm coaxial termination has been constructed with a voltage standing-wave ratio less than 1.05 at 960 Mc when cooled by immersion in liquid helium (4.2° K). This termination is very "quiet" in terms of available thermal noise power, which equals kTB, where k is Boltzmann's constant (1.38×10^{-23} joules/°K), T is the temperature (in °K), and B is the bandwidth (in cps). The available noise power from a 4.2°K termination is 5.8×10^{-17} watts, or -132 dbm, over a 1-Mc bandwidth. This instrument has proved to be invaluable in the accurate evaluation of low-noise-amplifier performance, antenna temperature measurements, and radio-astronomy calibrations.

A Stoddart Aircraft[1] 50-ohm "N" connector termination was modified by replacement of the resistive insert with a 63-ohm room-temperature unit. Several inserts were tried until the VSWR desired was obtained when the termination was cooled to the temperature of liquid helium.

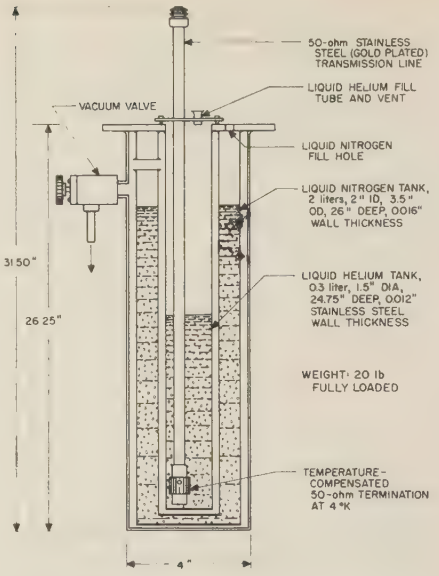


Fig. 1.—Construction details of liquid-helium dewar.

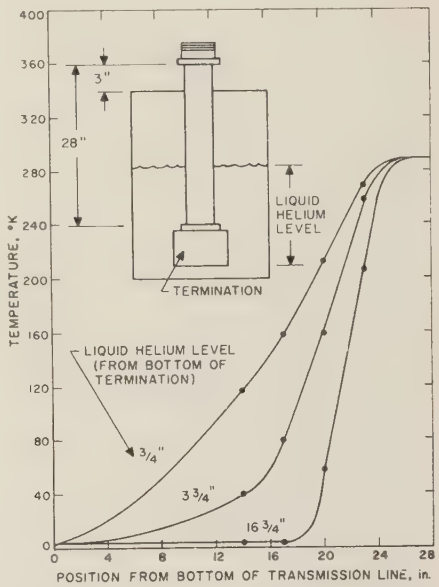


Fig. 2—Plot of temperature distribution on center conductor of coaxial transmission line with liquid-helium-cooled termination.

A 28-inch-long coaxial line was constructed from stainless steel tubing with an inner conductor of 0.188-inch OD, 0.035-inch wall thickness, and an outer conductor of 0.500-inch OD and 0.035-inch wall thickness. Both were plated with 50 micro-inches of copper and 40 micro-inches of gold.

A portable dewar was constructed from standard stainless-steel tubing to hold $\frac{1}{3}$ liter liquid helium and to give approximately 6 hours of active use between refills. The details of the construction are shown in Fig. 1.

The temperature distribution along the transmission line was measured with thermocouples and plotted as shown in Fig. 2 as a function of liquid-helium level. The insertion loss of the transmission line was measured with a Weinschel[2] dual-channel

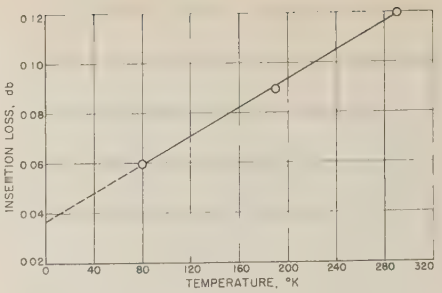


Fig. 3—Insertion loss of plated coaxial line plotted vs temperature.

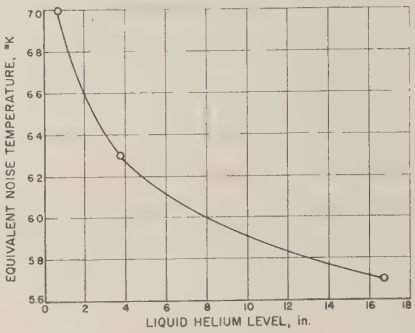


Fig. 4—Calculated equivalent noise temperature of plated coaxial line and liquid-helium-cooled termination plotted vs liquid-helium level.

insertion-loss test set at three temperatures, as shown in Fig. 3. The high insertion loss was assumed to be caused by insufficient plating thickness. The equivalent noise temperature of the transmission line and termination was calculated by separating the line into five sections, each with an average temperature and transmission coefficient. The equivalent noise temperature for a termination and five sections is

$$T = (1 - t_5)T_5 - (1 - t_4)t_5T_4 + (1 - t_3)t_4t_5T_3 + (1 - t_2)t_3t_4t_5T_2 + (1 - t_1)t_2t_3t_4t_5T_1 + t_1t_2t_3t_4t_5T_t,$$

where

T = equivalent noise temperature,
T_n = thermal temperature of nth section from the termination,
t_n = transmission coefficient of nth section from the termination,
T_t = termination temperature.

The equivalent noise temperature was calculated and plotted as shown in Fig. 4 as a function of liquid-helium level.

A second unit is under construction for use at 2388 Mc. The coaxial transmission line will have a larger diameter and thicker plating in order to reduce line loss and, hence, temperature variation with liquid-helium level.

Acknowledgment

The author wishes to acknowledge the assistance of G. Levy, who suggested the project, R. Clauss, who constructed the dewar, and K. Wallace, who performed the measurements.

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* Received by the IRE, March 1, 1961; revised manuscript received, March 27, 1961. This paper presents the results of one phase of research carried out at the Jet Propulsion Lab., Calif. Inst. Tech., Pasadena, under contract no. NASw-6, sponsored by the Natl. Aeronautics and Space Administration.

[1] Stoddart Aircraft Radio Co., Inc., Hollywood, Calif.

[2] Weinschel Engineering Co., Kensington, Md.

Additional Negative-Resistance Oscillation Modes*

Several modes of oscillation can exist in negative-resistance oscillators. A relaxation mode, a mode operating within the negative-resistance region of the characteristic, and a cosecant mode have been reported.[1] A different set of modes (in effect "class-C" modes) operate around bias points at the peak and valley of the tunnel-diode negative resistance characteristics. Fig. 1 illustrates such a class-C oscillation in a simple parallel LC circuit connected in series with a tunnel diode of characteristics shown in Fig. 2. The output voltage developed across the tank circuit with this mode of oscillation is shown in Fig. 3. Normally the mode is self starting, but under certain bias conditions an external trigger voltage pulse may be used to start the oscillation. Similar oscillations have been achieved around the valley point with voltage swings of 350 mv (peak to peak) for germanium diodes. The operation at frequencies above a few megacycles has not been explored. The lower frequency limit where sinusoidal waveforms have been observed is below 1 cps.

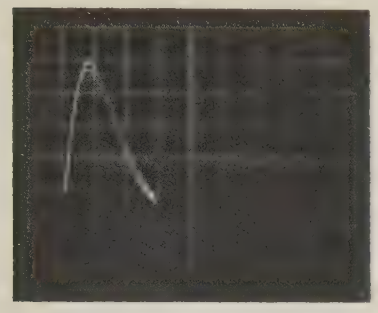


Fig. 1—A class-C oscillation cycling about the characteristic curve of diode No. 355 when the dc bias point is at the current maximum. The vertical and horizontal calibrations are 0.1 ma and 50 mv per large division, respectively.

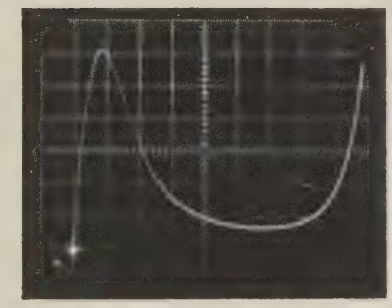


Fig. 2—Germanium tunnel diode No. 355 at room temperature. The vertical and horizontal calibrations are 0.1 and 50 mv per large division, respectively.

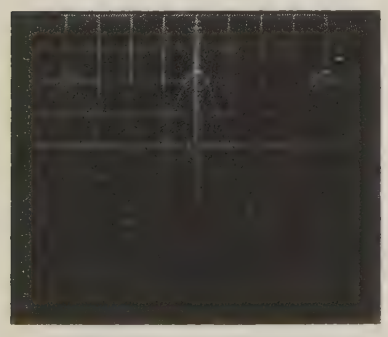


Fig. 3—Voltage output across the tank circuit with the limit cycle of Fig. 1. The total harmonic distortion here is less than 1 per cent. The vertical and horizontal calibrations are 50 mv and 50 μsec per large division, respectively.

* Received by the IRE, March 17, 1961.

[1] C. Brunetti, "Clarifications of average negative resistance with suggestions of its use," PROC. IRE, vol. 25, pp. 1595-1616; December, 1937.

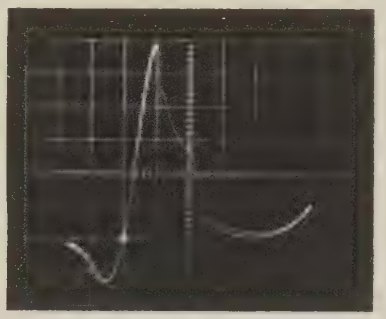


Fig. 4—The oscillation cycling about the characteristic curve of diode Nos. 357 and 383 connected back to back in a simple oscillating circuit. The bias point is at he peak of the tunnel current in the diode with the larger current. The vertical and horizontal calibrations are 0.1 ma and 100 mv per large division, respectively, with the origin being the bright spot.

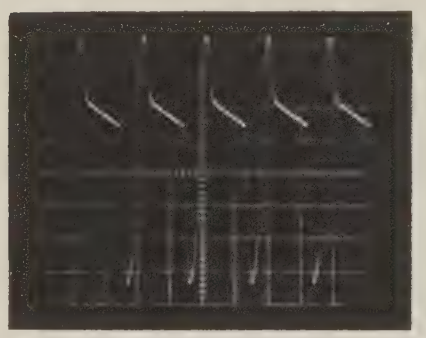


Fig. 5—The output voltage developed across the tank circuit in the oscillation described in Fig. 4. The vertical and horizontal calibrations are 100 mv and 50 msec per large division, respectively.



Fig. 6—The oscillation cycling about the characteristic curve of diode Nos. 357 and 390 connected in series. The horizontal scale is 100 mv per large division.

If two tunnel diodes are connected back to back (*i.e.*, in series opposition), the oscillation around the peak point of one diode may extend into the negative-resistance region of the second diode (see Fig. 4) particularly if this diode is of lower peak current. The swing may be as large as 750 mv (peak to peak) and a typical waveform is shown in Fig. 5. Oscillation amplitudes of over a volt may be obtained with a tunnel diode in series with a nontunneling forward-biased diode and the tank circuit as before. With a bias point near the peak of the tunnel diode, the oscillation may extend beyond the tunnel diode characteristic and into part of the nontunelling diode curve as indicated in Fig. 6.

The modes of oscillation in Figs. 4 and 6 require rather large peak-to-valley ratios, and therefore the germanium units used were lowered in temperature to improve the ratio to above 20:1. Such ratios are more commonly obtained at room temperature in gallium-arsenide diodes. A more complete discussion and analysis of oscillation modes in negative-resistance devices is in process.

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Tunnel-Diode Down Converters*

Similarities exist in two recent papers on tunnel-diode down converters[1,2] if considered in terms of the model shown in Fig. 1. Differences lie in the magnitude and variations assigned to the shot-noise current generator i_{nd}. The shunt-resonant conductance of the input and output circuits tuned to frequency ω_1 and ω_2 respectively, is represented by G_1 and G_2. The diode is represented by a two-port model bridged by a shot-noise generator. A similar model[3] shows that the diode admittance with a relatively large local oscillator voltage applied could be expressed in a Fourier series as

$$g_d = G_0 + 2G_{T_1}\cos\omega_3 t + 2G_{T_2}\cos 2\omega_3 t + \cdots . \quad (1)$$

In addition to the local oscillator voltage at frequency $\omega_3(=\omega_1+\omega_2)$, only two other voltages at frequencies ω_1 and ω_2 are allowed to exist across the diode by its associated circuits. When these voltages are small compared with the local oscillator voltage, the small signal diode currents are given by taking the product of the small signal diode voltage (v_1-v_2) and the diode conductance g_d. In this product, the signal currents of interest are those selected by the input and

* Received by the IRE, March 20, 1961; revised manuscript received, May 15, 1961.

[1] K. K. N. Chang, *et al.*, "Low-noise tunnel-diode down converter having convers on gain," PROC. IRE, vol. 48, pp. 854-858; May, 1960.

[2] D. I. Breitzer, "Noise figure of tunnel-diode mixer," PROC. IRE (Correspondence), vol. 48, pp. 935-936; May, 1960.

[3] M. J. O. Strutt, "Noise figure reduction in mixer stages," PROC. IRE, vol. 34, pp. 942-950; December, 1946.

TABLE I
EQUIVALENT ANALYSIS SYMBOLS

This Analysis	G_0	G_1	G_2	G_g	G_L	$\bar{G}_1$	$\bar{G}_2$	$(G_{T_1}/\bar{G}_1)^2$	G_{e_0}	G_{e_1}	T_0	T
Chang, *et al.*	G_0	G_1	G_2	G_g	G_L	$\bar{G}_1$	$\bar{G}_2$	$\bar{G}_2\lambda/\bar{G}_1$	$G_e = \dfrac{e(I_0 - I_{0r})}{2kT}$	—	T_0	T
Breitzer	g_0	—	—	$\dfrac{1}{r_1}$	$\dfrac{1}{r_2}$	—	—	γ^2	$\dfrac{q(I_{0f} + I_{0r})}{2kT}$	$\dfrac{q(I_{1f} + I_{1r})}{2kT}$	T_1	T_2

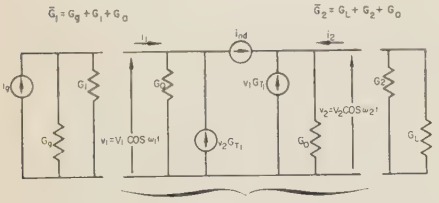


Fig. 1—Noise model of tunnel-diode down converter.

output circuits and are obtained by ignoring all components except those at frequency ω_1 and ω_2

$$i_1 = (G_0 V_1 - G_{T_1} V_2) \cos \omega_1 t,$$
$$i_2 = (-G_{T_1} V_1 + G_0 V_2) \cos \omega_2 t. \quad (2)$$

Eqs. (2) are the equations used by Breitzer and corresponds to Chang's (2) and (3) at resonance with the changes in the sign of G_{T_1} and v_2 to match the assumed directions for currents and voltages. The most significant terms of (1) here correspond to the two terms obtained from taking the derivative of Chang's (1) with respect to the local oscillator voltage (Table 1 shows equivalence of terms). Chang assumes that the equivalent saturated diode current for computing G_e was the diode current at the operating point $I_0 = I_{0f} - I_{0r}$. Breitzer assumes not only that the equivalent saturated diode current has an average value given by the sum of the absolute values of the avalanche breakdown current I_{0r}, and the Esaki current I_{0f} at the operating point, but that the equivalent saturated diode current is amplitude modulated by the local oscillator.

Computing the noise figure for Chang's assumptions from Fig. 1, we obtain

$$F = 1 + \frac{T}{T_0}\left\{\frac{G_1}{G_g} + \left(\frac{\bar{G}_1}{G_{T_1}}\right)^2 \frac{G_2 + G_L}{G_g} + \left[1 + \left(\frac{\bar{G}_1}{G_{T_1}}\right)^2\right]\frac{G_e}{G_g}\right\}. \quad (3)$$

In (3), the first term results from noise in the signal source, the second term from input-preselector circuit noise, the third from output-tuned circuit and load noise, and the last term from diode noise. Eq. (3) is different in form but identical in content with (26) of Chang *et al.*

Evaluation of the individual terms of (3) for Chang's two examples, results in

$$F_{Ge} = 1 + 0 + 2.32 + 0.30 = 3.62$$
$$= 5.6 \text{ db}^4 \text{ with } 6.0 \text{ db transducer gain} \quad (3a)$$

$$F_{GaAs} = 1 + 0 + 1.14 + 0.21 = 2.35$$
$$= 3.7 \text{ db with } 22.7 \text{ db transducer gain.} \quad (3b)$$

If *LO* modulation of the equivalent saturated diode current is considered, G_e becomes a function of time and may be expressed in a Fourier series as indicated by Breitzer's (6)

$$g_e(t) = G_{e_0} + 2G_{e_1} \cos \omega_3 t + 2G_{e_2} \cos 2\omega_3 t + \cdots. \quad (4)$$

Breitzer has shown that this consideration results in a different noise-figure expression. Using the substitution shown in Table I and adding the terms to account for G_1 and G_2, Breitzer's (5) becomes

$$F = 1 + \frac{T}{T_0}\left\{\frac{G_1}{G_g} + \left(\frac{\bar{G}_1}{G_{T_1}}\right)^2 \frac{G_2 + G_L}{G_g} + \left[1 + \left(\frac{\bar{G}_1}{G_{T_1}}\right)^2\right]\frac{G_{e_0}}{G_g} - \frac{\bar{G}_1}{G_{T_1}}\frac{2G_{e_1}}{G_g}\right\} \quad (5)$$

Eq. (5) has one more term than (3). This term results from shot-noise currents in one of the two allowed frequency bands being amplitude modulated by the *LO* which produces correlated shot-noise currents in the other allowed frequency band. When these correlated shot-noise currents are converted to the same frequency band by the small signal properties of the device, the correlation is negative as is shown by the sign of the last term of (5).

Evaluation of the individual terms of (5), in the same order, for the two operating points of a GE ZJ56 (germanium) given by Greene[5] results in

$$F_{Ge_1} = 1 + 0 + 0.58 + 14.92 - 1.24 = 15.3$$
$$= 11.8 \text{ db with } 5.4 \text{ db transducer gain} \quad (5a)$$

$$F_{Ge_2} = 1 + 0 + 0.36 + 9.30 - 1.51 = 9.15$$
$$= 9.6 \text{ db with } 3.0 \text{ db transducer gain.} \quad (5b)$$

In (3a), the shot-noise term is small compared to the G_L/G_g term. We see here the relative unimportance of the shot-noise term; *i.e.*, whether

$$G_e = \frac{q}{2kT}(I_{0f} - I_{0r}) \quad (6)$$

or

$$G_{e_0} = \frac{q}{2kT}(I_{0f} + I_{0r}) \quad (7)$$

is employed for the equivalent diode shot-noise conductance; the calculated noise figure is essentially unchanged. In (5a) and (5b) terminations have been selected to reduce the load-conductance noise resulting in a large shot-noise term, which makes important the proper choice of (7) for shot-noise conductance.

The noise-figure expression derived by Breitzer differs in two ways from that derived by Chang. The effects of these differences, however, are made small by using high-conductance terminations as Chang, *et al.*, have done in their experimental examples. By allowing the equivalent shot-noise conductance to approach, or exceed, either or both of the input or output conductances, the diode noise is not suppressed. Therefore the more exact noise-figure expression derived by Breitzer gives better agreement with experimental measurements made with other than near-optimum terminations. It appears, then, that Breitzer has derived the more exact noise-figure expression, which Chang, *et al.*, have better minimized.

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[4] The reason for the difference between this computed noise figure and the 4.4 db computed by Chang, *et al.*, is not clear, but both agree reasonably well with the measured value of 5.2 db given by Chang, *et al.*

[5] J. C. Greene and E. W. Sard, "Experimental tunnel-diode mixer," PROC. IRE (Correspondence), vol. 49, pp. 350–351; January, 1961.

Excess Noise in Microwave Mixer Crystals*

Investigations of noise in dc biased silicon and germanium diodes have shown[1–6] that excess noise is usually the dominating factor, particularly at low frequencies, with a spectral distribution given by

$$W(f) = K(1/f^\alpha), \quad (1)$$

where K and α are constants, and f is the frequency. Most of the measurements have

* Received by the IRE, April 7, 1960.

[1] P. H. Miller, "Noise spectrum of crystal rectifiers," PROC. IRE, vol. 35, pp. 252–256; March, 1947.
[2] H. C. Torrey and C. A. Whitmer, "Crystal Rectifiers," MIT Rad. Lab. Ser., McGraw-Hill Book Co., Inc., New York, N. Y., vol. 15; 1948.
[3] H. C. Montgomery, "Electrical noise in semiconductors," *Bell. Sys. Tech. J.*, vol. 31, pp. 950–975; September, 1952.
[4] F. J. Hyde, "Measurements of noise spectra of a point contact germanium rectifier," *Proc. Phys. Soc.* (London), vol. B66, pp. 1017–1024; December, 1953.
[5] D. K. Baker, "Flicker noise in germanium rectifiers at very low- and audio-frequencies," *J. Appl. Phys.*, vol. 25, pp. 922–924; July, 1954.
[6] A. Hendry, "The temperature dependence of noise temperature ratio in germanium diodes," *Brit. J. Appl. Phys.*, vol. 9, pp. 458–460; November, 1958.

been performed at frequencies below 1 Mc and those made at higher frequencies have been restricted to the normally used intermediate frequencies of microwave receivers. It is found that α is close to unity.[7] However, measurements with dc excitation can give only a qualitative indication of the noise performance to be expected of a mixer crystal in normal use since the actual dynamic operating conditions of a large-amplitude RF drive with a small reverse bias are rather different. The few data which are available of excess noise with RF excitation are restricted to certain fixed frequencies,[2,7-9] and indicate that (1) holds at least up to 45 Mc with $\alpha=1$. The only measurements covering a range of frequencies,[10] 10 to 60 Mc, also indicate that $\alpha\simeq 1$. In view of the comparatively few results available at the higher frequencies, and the important and wide application of these devices, measurements of noise temperature of silicon point-contact diodes have been made over the wide frequency range of 25 cps to 80 Mc.

In the first series of measurements a batch of new, and previously unused, silicon point-contact crystals of types SIM2 and SIM5 (CV2154/5) were tested in broadband mixers over the frequency range 300 kc to 80 Mc. At the higher frequencies the source noise was removed by a cavity filter, and at low frequencies by means of a balanced mixer technique. In each case the crystal noise was compared with that from a standard noise diode. The incident microwave power was adjusted to give a rectified crystal current of 1 ma, which is typical of the values normally used. The resistance of the dc network associated with the mixers was 80 ohms, resulting in a reverse bias of 0.08 volt. Some reverse bias is inevitable, and gives rise to a small increase in crystal noise. The value is quoted here for comparison purposes.

Some typical crystal noise measurements are illustrated in Fig. 1. The results obtained with each crystal are consistent and repeatable, but the imperfection of the manufacturing techniques, even with present-day resources, is shown by the wide variation from crystal to crystal. It may also be seen that none of the crystals tested obeys the $1/f$ rule over the whole frequency range. The curves are all of the same general shape showing that at low frequencies the slope increases to give a value for $\alpha\simeq 1$, while at high frequencies the crystal noise becomes nearly constant and presumably equal to the sum of thermal and shot noise. Extrapolation seems to indicate that excess noise becomes negligible at a frequency of about 100 Mc. For the best crystal tested the $1/f$ law is not obeyed even at frequencies as low as 300 kc; for the bulk of the crystals this relation is only approached below 5 Mc. Thus the view that (1) holds with $\alpha\simeq 1$ at frequencies up to 45 Mc and above must be revised. Extrapolation of the curves indicates that the contributions of thermal and shot noise together correspond to a noise temperature ratio of 0.6 db for the best specimen and 3.0 db for a "typical" crystal.

In order to check how accurately, and over what range, the f^{-1} variation holds at lower frequencies, the noise temperature of one of the crystals was measured over the wide frequency range 25 cps to 30 Mc and for various values of the microwave driving power. The results, of which Fig. 2 is typical, show that the $1/f$ law is obeyed quite accurately from 25 cps to about 300 kc. It is thought that these are the first measurements taken continuously over such a wide frequency range.

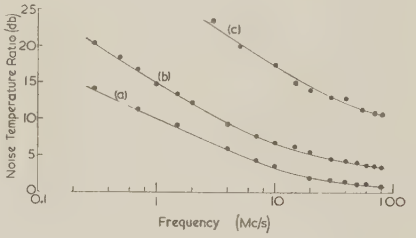


Fig. 1—Variation of noise temperature ratio with frequency. (a) Best crystal. (b) "Average" crystal. (c) Worst crystal.

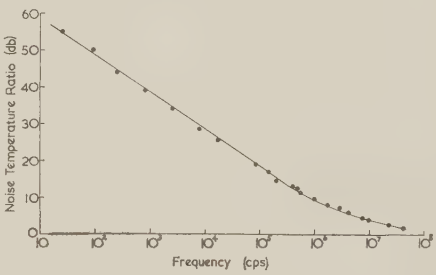


Fig. 2—Variation of noise temperature ratio over frequency range 25 cps to 80 Mc.

It is clear that where the highest sensitivities are required the choice of a mixer crystal for a microwave receiver must be made with great care, and a large number should be tested before the final selection is made since the variation in performance is considerable. Furthermore, when a good crystal is available the noise factor of a receiver can often be further reduced by a reduction in the IF frequency, although the latter also depends on other factors. It appears that although at present excess noise makes a large contribution to mixer noise, further improvement in manufacturing techniques will move the transition region between $\alpha=1$ and $\alpha=0$ to progressively lower frequencies.

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[7] P. D. Strum, "Some aspects of mixer crystal performance," Proc. IRE, vol. 41, pp. 875–889; July, 1953.
[8] G. R. Nicoll, "Noise in silicon microwave diodes," *Proc. IEE*, vol. 101, pt. 3, pp. 317–324; September, 1954.
[9] L. K. Anderson and A. Hendry, "An investigation of the properties of germanium mixer crystals at low temperatures," IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 393–398; October, 1958.
[10] M. E. Sprinks, G. T. G. Robinson, and B. G. Bosch, "The frequency dependence of noise temperature ratio in microwave mixer crystals," *Brit. J. Appl. Phys.*, vol. 8, pp. 275–277; July, 1957.

WWV and WWVH Standard Frequency and Time Transmissions*

The frequencies of the National Bureau of Standards radio stations WWV and WWVH are kept in agreement with respect to each other and have been maintained as constant as possible with respect to an improved United States Frequency Standard (USFS) since December 1, 1957.

The nominal broadcast frequencies should, for the purpose of highly accurate scientific measurements, or of establishing high uniformity among frequencies, or for removing unavoidable variations in the broadcast frequencies, be corrected to the value of the USFS, as indicated in the table below. The corrections reported have been arrived at by means of improved measurement methods based on LF and VLF transmissions.

The characteristics of the USFS, and its relation to time scales such as ET and UT2, have been described in a previous issue,[1] to which the reader is referred for a complete discussion.

The WWV and WWVH time signals are also kept in agreement with each other. Also they are locked to the nominal frequency of the transmissions and consequently may depart continuously from UT2. Corrections are determined and published by the U. S. Naval Observatory. The broadcast signals are maintained in close agreement with UT2 by properly offsetting the broadcast frequency from the USFS at the beginning of each year when necessary. This new system was commenced on January 1, 1960. A retardation time adjustment of 20 milliseconds was made on December 16, 1959; another retardation adjustment of 5 milliseconds was made at 0000 UT on January 1, 1961.

WWV Frequency
With Respect to U. S. Frequency Standard

1961 April	Parts in 10†
1	−150.7
2	−150.8
3	−150.4
4	−150.0
5	−150.2
6	−150.2
7	−150.4
8	−150.5
9	−150.6
10	−150.5
11	−150.2
12	−150.0
13	−150.3
14	−150.8
15	−150.3
16	−150.2
17	−150.2
18	−150.0
19	−149.9
20	−149.8
21	−149.7
22	−149.7
23	−149.8
24	−149.3
25	−149.6
26	−149.2
27	−149.5
28‡	−149.2
29	−150.3
30	−150.2

† A minus sign indicates that the broadcast frequency was low. The uncertainty associated with these values is $\pm 5\times 10^{-11}$.
‡ The frequency was decreased 0.8×10^{-10} at 1900 UT on April 28, 1961.

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Boulder, Colo.

* Received by the IRE, May 25, 1961.
[1] "National Standards of Time and Frequency in the United States," Proc. IRE, vol. 48, pp. 105–106; January, 1960.

On the Hues Seen in Fox-Color Images*

At a session of the National Academy of Sciences, November 20, 1957,[1] Dr. E. H. Land showed fine color pictures projected from only two monochrome slides, astounding the audience, particularly—I would think—those of us who had given much thought to rendition of color, such as in color television. A person or object had been photographed simultaneously with two cameras on black-and-white film, once through a red filter Wratten No. 24, and once through a green filter Wratten No. 58. Copied on slides, the two images were projected in register, the former through red filter No. 24, the other without color filter. The results were very pleasing polychrome images comprising not only red and green (=minus red) but, unexpectedly, also yellow and blue.

The effect had first been noted by W. F. Fox in 1914.[2] He had aimed at two-color pictures with alternate frames using a red and a green filter both for exposure and projection. When the image was too dim he removed the green projection filter, and not only gained light, but also saw many more hues than the mixtures of red and green he had seen before. In 1930, A. Bernardi thought of the same trick for the same reason, had the same surprise ("the theory of the method is perhaps incomplete"[3]). Not for all objects do these images show such unexpected hues. Dr. Land, in his study of images that do show them, has demonstrated that even remarkably modified clues can still make us see them; he and others[4] have tried to find laws relating the colors seen to the stimuli shown. I, myself, to begin with was willing to credit the mind of the viewer with undreamt-of skill in the interpretation of clues. My aim was to find out how many hues a scheme with such limited information can render faithfully, and where it had to fail. If, as we think, definition of a color requires three parameters, either the intensity of three primaries or else a value for the dominant hue (wavelength), for brightness, and for its saturation, then how can we by this method manage with only two parameters for each area, the brightnesses of two superimposed projections? And if we can, one should confidently seek for much simplified color television systems. In 1958, I began a series of systematic tests.

As Dr. Land had shown, superimposed projection of a red wedge crossed by a grey wedge merely shows shades of one pink hue. Recognition of objects is a required condition, thus color test charts also fail. I selected 25 measured hues evenly distributed over the spectrum, each sample in three saturations, and mounted them in five rows in color sequence. The resulting Fox-color images showed only one red in various saturations, one green (minus red) in various shades of (less) saturation, and between them a few near-white colorless areas for the yellow samples. Clearly, it was necessary to study numerous and varied images, and then to try and find rules by induction. Since pictures offer much greater diversity than real objects, and are easily available for repeat and comparison, I selected a dozen full page color pictures from well-printed magazines, ranging from simple, strong to pale and subtle colors, from photographs of fruit bowls to people, landscapes, and to abstract color patches, with preference for well-distributed variety of moderate color areas, as distinct from only one or two hues and from important colors in fine details which might suffer from poor registration. All these were photographed through the same lens in daylight on Kodak Plus X panchromatic 35 mm film, two or three exposures varied 1:2, through red filter No. 24, through green filter No. 58, and later also through bluish-green filter No. 64, whose transmissions are plotted from Eastman data in Fig. 1. There were also color photographs on Kodachrome for reference. All negatives were developed in Kodak D 76, 1:1, 8 minutes at 68° F. All tested negatives were equally usable. They were contact-printed on Kodak positive film with various exposures, developed in D 72, 1:2, at 68°F; all prints tested led to the same observations.

Pairs of these prints were first examined by projection with two identical slide projectors side by side with their axes parallel; one without, the other with, red filter No. 24. Fine register is easily obtained, but projection proved not so flexible and convenient as desired. I therefore built a viewer as sketched in Fig. 2. The eye looks through magnifying lens L of 3-inch focal length under 45° at an optically flat glass plate M_1, whose front surface is anti-reflection coated, and whose rear face is mirror-coated for approximately equal transmission and reflection of all colors under 45°. The transmitted image is that of the "red" slide S_2 backed by a spaced diffuser D and red filter F, illuminated via ordinary mirror M_2. The reflected image is that of the "grey" slide S_1 backed by a spaced diffuser D. Parallel light, indicated by arrows, will illuminate both slides equally. Both slides are seen at the same distance; one of these is easily moved about in its plane for very satisfactory register. Ratio of illuminations could be controlled by shading; but it was found more convenient to provide two lamps No. 47, each in its own reflector and with separate control resistor, mounted so that each illuminated only one slide. Change of "white" hue with lamp current proved harmless. All observations were made with this viewer, many later rechecked with the two projectors, but nothing more or different was noted.

All pairs of slides were methodically and repeatedly scrutinized, again with varied light levels and with varied ratios of brightness; it was noted what colors, if any, were seen in each area and how these compared with the original. From all these data I noted:

1) The color effect is not critical with brightness, is washed out in very bright light and lost in very dim pictures; over the wide useable range the hues seen do not change.

2) Moving one's eyes reveals no afterimage.

3) As soon as one fixes one's gaze, the pictures are nearly final, but (while they do not seem to change) one gets a little more conscious in time of colors other than red or green, such as blue or yellow.

4) Keeping the grey image unchanged and raising red, pictures change from drab neutral to "colored," even when no hue besides red is noted; "colored" means pleasantly undrab, not merely tinted as if seen through tinted glasses.

5) I can see all shades of grey and all shades of that red, some shades in green (=minus red), perhaps in yellow, no shades in other hues.

6) Hues other than red and green were noted only (I think) when known, such as yellow bananas, blue sky, also blue water on some pictures. Listing all hues seen: only one hue of red, one of green, one yellow at a time (this most sensitive of hues shifts towards orange when the red image is turned up), one blue, several orange hues, a dull brown and

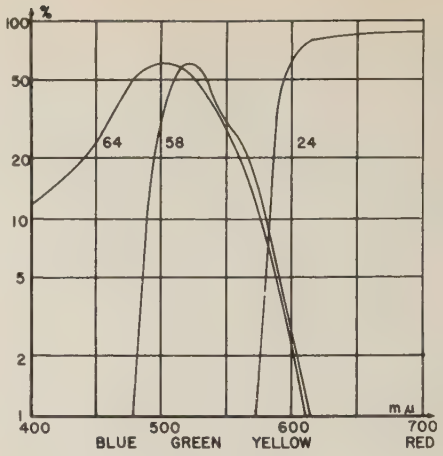


Fig. 1—Transmission of filters no. 24, 58, 64.

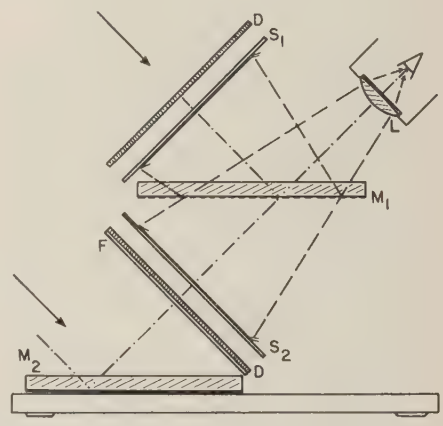


Fig. 2—Optics of slide-pair viewer.

* Received by the IRE, March 27, 1961.

[1] See, for example, E. H. Land, "Color vision and the natural image," *Proc. Natl. Acad. Sciences*, pt. I, vol. 45, pp. 115–129, January, 1959; pt. II, vol. 45, pp. 634–644; April, 1959. Also, "Experiments in color vision," *Sci. Amer.*, vol. 200, pp. 84–99; May, 1959; and letter (by E. H. Land) to *Sci. Am.*, vol. 201, pp. 16, 18, 20 and 22; September, 1959.

[2] W. F. Fox, "Inventor and W. H. Hickey, Manufacturer", British Patent No. 636; July, 1914. I am much indebted to Dr. E. H. Land and to R. T. Kriebel of Polaroid Corp. for this reference and many others.

[3] A. Bernardi, *et al.*, British Patent No. 329,438; May, 1930. Also British Patent No. 335,310; September, 1930.

[4] M. M. Woolfson, "Some new aspects of color perception," *IBM J. Res. & Dev.*, vol. 3, pp. 312–325; October, 1959.

a nondescript color, probably purple, no others.

7) Unless expected, yellow looks white and orange looks red.

8) No hues other than that red and that green can be identified on abstract pictures, even with effort to memorize them.

9) Except for red, then green, yellow and blue, colors are not very strong; one tends to be uncertain about their hue; one notes hues in orange, though not correct.

10) Pictures are (of neccssity?) never strident, since seen colors are pleasantly complementary. Indeed one is constantly reminded of Wilhelm Ostwald's ideas on harmonious color combinations,[5] pairs, triples, and quadruples evenly spaced on his 100-hue color circle. As near as I can judge, the red is his No. 79 (>660 mμ), the yellow is his No. 04 (576 mμ), the green is his No. 29 (490 mμ), and the blue is his No. 54 (465 mμ).

11) Since—I suspect—one tends to equate the plausible with the natural, and the strident with the unnatural, one often considers the pleasant hues as natural; yet they are wrong.

12) Pairs of pictures taken with green filter No. 58 render blue very dark, since that filter cuts off blue. Therefore I selected No. 64, a slightly bluer green that passes blue, and repeated most pairs with Nos. 24 and 64. Blue, when seen, *e.g.*, water in a lagoon, is then a bright blue, yellow now a little darker.

13) An order of slides showing most, to few, to no varied hues, corresponds to the order from most familiar to most abstract objects.

14) Since varying of technical conditions such as exposure, printing, and brightness does not, or only slightly, affect these observations, and since the successful and other pairs were all processed alike, I think it most unlikely that I missed one particular set of processing conditions that would have yielded much better results.

The tests led me to suspect that one guesses most of the hues (other than red) from memory. Only a few objects such as fruit were highly successful, many others showed little, and many more no, colors other than red, however long one tries to memorize them. I was pleased only with two out of a dozen images; yet they were not actually correct. My tentative conclusions were that there are two ways to communicate color. The one, according to familiar concepts, informs us without aiding clues, is indispensable at least when we see an object the first time, and requires three parameters. The other transmits much less information (fewer parameters), but relies heavily on the viewer's memory. Indeed it aids the memory rather than is aided by it. One is reminded of a very poor telephone link where one cannot guess words without aid of familiar context. Also that we are unaware of the retinal blind spot shows that our mind can supply what we "see" in these areas.

Since then, there was time to plan some more pointed tests; two occurred to me. The failure to see colors in test charts has been blamed on their extremely unbalanced distribution. Therefore, I assembled the same set of 25 color samples in a seemingly random test chart, actually—for even distribution—so arranged that a), there was in each quarter of the chart at least one hue from each quarter of the spectrum and b), no two patches of similar hue were near each other. This did not improve matters; no more hues can be seen than in the ordered test chart.

Then I wanted to test familiar objects that had been dyed an unfamiliar color. I chose bananas, whose yellow hue is almost irrepressible, and whose even-shaded large surfaces are most convenient. Using filters 24, 58, and 64, photographs as above were taken of mixed heaps of bananas picked for similar size and shape, some bright yellow, some strong green (plantain, Musa paradisiaca) and some mixed-in, painted rather strong skyblue,[6] but approximating the brightness, saturation and surface of their neighbors. While doubting to see them blue, I had expected to see green bananas (a familiar sight here). Actually, with filters 24 and 58, the yellow bananas look a natural yellow, the green plantain look nearly the same yellow, but much less saturated and so look the light-blue bananas, the dark-blue banana tending towards grey-green. With filters 24 and 64, yellow bananas look as before, green plantain as before, the blue bananas rather light, a pale green,—no blue.

As a noted painter[7] wrote: "It would be interesting if some real authority investigated carefully the part which memory plays in painting. . . . The object message . . . has been transmitted in code. . . . It reaches the canvas a cryptogram. Not until it has been placed in the correct relation to everything else that is on the canvas can it be deciphered."

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[5] W. Ostwald, "Farbkunde," S. Hirzel, Leipzig, Germany, 1923, also "Die Farbenfibel," 2nd ed., UNESMA, Leipzig, Germany, 1917.

[6] Winsor & Newton gouache, cerulean blue and zinc white 1:1; 1:5 thinned with water; a thin, just-opaque coat dries without gloss.

[7] Sir Winston Churchill, quoted in E. H. Gombrich, "Art and Illusion," Bollingen Series, Pantheon Books, Inc., New York, N. Y., pp. 38–39; 1960.

Relative Error Analysis*

In recent years the concept of sensitivity[1] has become one of the useful tools for servo-system design. In another context, that of error analysis, this concept is also quite useful, but its merits do not appear to be widely appreciated. Some of the salient features of this viewpoint are illustrated here.

* Received by the IRE, March 28, 1961.

[1] J. G. Truxal, "Automatic Feedback Control System Synthesis," McGraw-Hill Book Co., Inc., New York, N. Y., pp. 120–127; 1955.

The usual methods for analyzing the propagation of error in an experiment deal with absolute errors and utilize error expressions of the form

$$(\Delta F)_x \approx \frac{\partial F}{\partial x}\Delta x; \qquad (\Delta F)_y \approx \frac{\partial F}{\partial y}\Delta y, \quad (1)$$

where $F=F(x, y)$, and $(\Delta F)_x$ is the absolute error in F resulting from Δx, the absolute error in x. In contrast, sensitivity deals with relative (or per cent) errors and relates the relative error in the results of an experiment to the relative sources of error. These relative errors have the form

$$\frac{\Delta F}{F}; \qquad \frac{\Delta x}{x}; \qquad \frac{\Delta y}{y}.$$

Then if S_x^F is defined as the sensitivity of F to a change in x,

$$S_x^F = \frac{x}{F}\frac{\partial F}{\partial x}, \quad (2)$$

relative error expressions can be written in the form

$$\left(\frac{\Delta F}{F}\right)_x \approx S_x^F \frac{\Delta x}{x}; \left(\frac{\Delta F}{F}\right)_y \approx S_y^F \frac{\Delta y}{y}. \quad (3)$$

Equations having the form of (3) are the key to relative error analysis. Just how the $(\Delta F/F)_i$ for a function, or for an experiment, should be combined to obtain an over-all error figure depends on the use to be made of this figure and also on the nature of the sources of error (*i.e.*, whether independent or correlated, and the shape—Gaussian or otherwise—of each error probability distribution).[2] An outside limit of error can be estimated simply by adding the absolute values of the $(\Delta F/F)_i$.

One simple example of this analysis is a study of the propagation of error in slide rule calculations. Since the scales of a slide rule are of a logarithmic nature, they have the useful property that, for any particular scale, the per cent reading accuracy is the same at all points on the scale. For the C and D scales (and their folded and inverted counterparts) on a ten-inch slide rule, this accuracy is somewhat better than ± 0.2 per cent. Now consider the quotient

$$Q = \frac{mno}{pqr}$$

and let it be assumed that the limiting error on each factor is the error in setting the number into the slide rule. The sensitivity of Q to an error in a numerator factor, such as m, is

$$S_m^Q = \frac{m}{Q}\frac{\partial Q}{\partial m} = \frac{m}{\frac{mno}{pqr}}\frac{no}{pqr} = +1.$$

In a similar fashion, the sensitivity of Q to an error in a denominator factor is found to be -1. Hence, the ± 0.2 per cent error of setting each factor into the slide rule will contribute ± 0.2 per cent to the total error in Q. In addition, there is another ± 0.2 per cent error in reading out the answer, Q. Thus, the outside limit of error (as against the prob-

[2] Y. Beers, "Introduction to the Theory of Error," Addison-Wesley, Reading, Mass., pp. 26–36; 1957.

able error, which would be somewhat less) of using a ten-inch slide rule to multiply and/or divide n numbers is simply

$$\% \text{ error} \leq \pm\, 0.2(n+1)\%.$$

In conclusion, some commonly met sensitivities are tabulated below to suggest the possibilities of relative error analysis. G may be a function of other variables, but not of x.

F	S_x^F
Gx	$+1$
$\frac{G}{x}$	-1
$G \pm x$	$\pm \frac{x}{F}$
Gx^n	n
Ge^x	x

If M and N are functions of x, then the following relationships may be convenient.

F	S_x^F
MN	$S_x^M + S_x^N$
$\frac{M}{N}$	$S_x^M - S_x^N$
$M \pm N$	$\frac{M}{F} \cdot S_x^M \pm \frac{N}{F} \cdot S_x^N$

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Autocorrelation Properties of Convoluted Optimum Finite Code Groups*

There has been a large amount of work done on the problem of finding binary sequences whose autocorrelation functions have uniformly low off-center peaks. This note presents some new results on this topic.

The search for optimum finite code groups has gone on for many years. An optimum code is a sequence of plus and minus ones whose autocorrelation function, as given by the expression

$$R_X(k) = \sum_{i=0}^{N-k} X_i X_{i+k}$$

has the properties:

$$R_X(k) = \begin{cases} N & k = 0 \\ 0 & k \text{ odd} \\ \pm 1 & k \text{ even } k \neq 0, \end{cases}$$

where N is the length of the sequence.

It is known that such sequences exist only for $N = 3, 4, 5, 7, 11$ and 13. In an attempt to produce sequences longer than 13 that have "good" autocorrelation functions, the author has investigated the autocorrelation functions of sequences formed from the convolution of optimum sequences.

The sequences are formed by convolving an optimum sequence of length N, and digit length m, with the same sequence of length N, but of digit length mN. That is, each digit in the original sequence is replaced by the sequence, multiplied by the value of that digit.

If $R_B(k)$ is the value of the autocorrelation function of the original sequence B, at a shift of k digits, then the autocorrelation function of the convolved sequence X, at a delay of k digits, is:

$$R_X(k) = R_B[k(\text{mod } n)]R_B(m) + R_B[n - k(\text{mod } n)]R_B(m+1),$$

where n is the length of the original sequence and m is the integral part of (k/n).

For basic sequences of length 3, 7, and 11, the ratio of $R_X(0)$ to the maximum off-center positive peak of $R_X(k)$ is n^2. A typical correlation function is shown in Fig. 1.

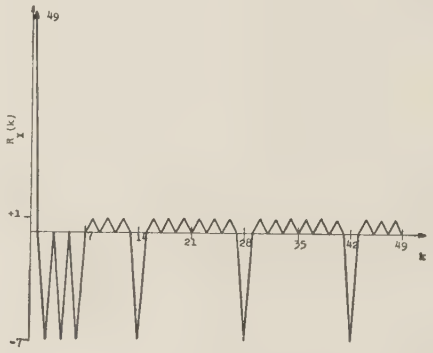


Fig. 1—Autocorrelation function of 7×7 sequence.

The autocorrelation functions of higher-order convolutions are being investigated. From a preliminary study, it would seem that the off-center positive peaks of the correlation functions have the value n^{k-2}, where k is the order of the convolution. Autocorrelation functions of sequences formed from the convolution of different optimum codes are also being investigated.

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[2] J. E. Storer and R. Turyn, "Optimum finite code groups," Proc. IRE, vol. 46, p. 1649; September, 1958.

* Received by the IRE, April 14, 1961.

An L-Band Traveling-Wave Parametric Amplifier*

The conventional cavity-type parametric amplifier has a narrow bandwidth and poor stability. The traveling-wave-type parametric amplifier tends to overcome these disadvantages by utilizing a broad-band microwave structure and an amplification mechanism which is unidirectional.[1] This note describes a traveling-wave parametric amplifier which operates around 1.35 Gc and provides a stable gain of approximately 10 db over approximately a 10 per cent band. The amplifier uses 10 Hughes HPA-2810 diodes spaced 3.8 cm apart. Each diode has a series inductance of approximately $\frac{1}{4}$ nanohenries and a static capacitance of about 1 pf for reasonable bias.

The amplifier consists of essentially two circuits: a transmission line for the signal and idling frequencies and a separate circuit for the pump frequency. The signal and idling frequencies propagate on a slab line[2] which is periodically loaded with the semiconductor diodes. Each diode is fed with a pump signal whose phase can be arbitrarily adjusted. The individual pump powers are supplied by a pump generator whose output is divided by means of a power divider into as many lines as there are diodes. Each diode can be individually back-biased by means of an external bias supply.

A drawing of the slab transmission line is shown in Fig. 1(a). The slab line consists of two flat plates and a cylindrical center conductor. The diodes are mounted periodically between the center conductor and one of the flat plates, resulting in a loaded-line impedance of 50 ohms. Each diode is fed with a properly phased pump voltage through a coaxial line. This line contains a bias stub which enables a dc bias voltage to be applied to the diode to cause its static capacitance to be at a desired operating point. A blocking capacitor is placed at the pump input end of each coaxial line to prevent the pump

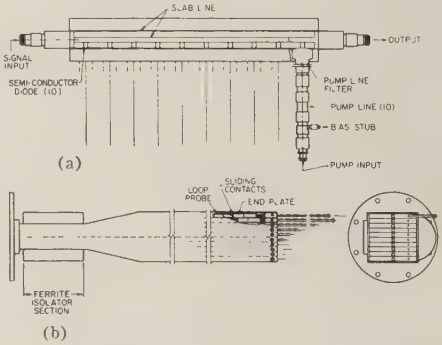


Fig. 1—(a) Signal transmission line of parametric amplifier. (b) Power divider and isolator section.

* Received by the IRE, February 27, 1961; revised manuscript received, March 23, 1961.

[1] C. V. Bell and G. Wade, "Circuit Considerations in Traveling-Wave Parametric Amplifier," 1959 IRE WESCON Convention Record, vol. 3, pt. 2, pp. 75–82.

[2] W. B. Wholey and W. N. Eldred, "A New Type of Slotted Line Section," Proc. IRE, vol. 38, pp. 244–248; March, 1950.

generator from shorting out the bias power supply.

A band-pass filter is located near the diode junction in each pump line. This filter prevents propagation of the signal, idling, and upper sideband frequencies toward the pump power divider while allowing transmission of the pump frequency.

The 10 coaxial pump lines are fed from the 10 outputs of a waveguide power divider, a drawing of which is shown in Fig. 1(b). The pump source is a 2 K 41 klystron which provides a power output of approximately 0.7 watt at a frequency of 2.64 Gc. The pump power is fed into a section of standard height *S*-band waveguide which is then divided into ten 6.35 mm height waveguide outputs. A loop probe is inserted into each waveguide output and attached to an end plate. This shorting plate is moveable and makes electrical contact with the walls by means of attached fingers. Each probe is attached to a rigid Amphenol Subminax connector which in turn connects through a length of Subminax coaxial cable to one of the pump inputs of the slab line. The pump phases are varied by moving the combination waveguide shorts and loop probes in or out.

The biases and pump phases were adjusted for an optimum gain over the band. Fig. 2 shows the forward gain characteristics of the amplifier for an average pump power per diode of approximately 50 mw. With slight readjustment of pump phases or diode biases, the gain near 1.42 Gc can be increased to above 30 db without much change in the rest of the gain curve. It appears that the gain is not due entirely to a pure traveling-wave type of interaction, but that the individual diodes are also contributing to the gain in a nontraveling-wave fashion.

When the amplifier is operating properly, it should have no reverse gain, and preferably a loss. The reverse loss is shown dotted in Fig. 2.

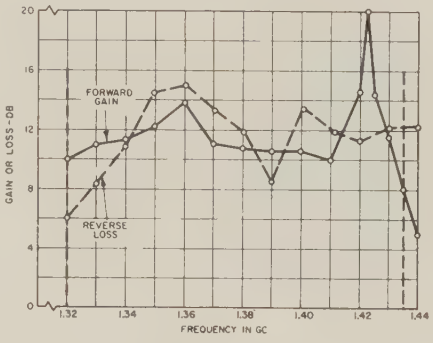


Fig. 2—Forward gain and reverse loss of parametric amplifier.

Noise figure measurements were made with the amplifier operating in the frequency range of 1.34 to 1.39 Gc and for gains varying from 10 to 15 db. The average single-channel noise figure was 4.0 db, with a probable error of ± 0.3 db.

Acknowledgment

The authors wish to acknowledge the advice and assistance of H. Heffner, J. Lepoff, and G. Wheeler during the course of this work.

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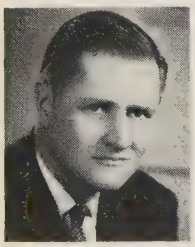
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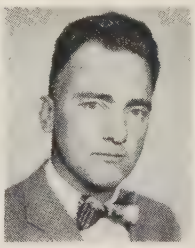
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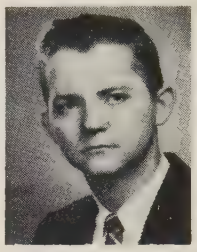


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He joined Bell Telephone Laboratories, Inc., Murray Hill, N. J., in 1936 where he was engaged in the design of inductors until 1953, when he became Components Development Engineer in charge of an organization devoted to fundamental development of inductors, capacitors, and resistors. In 1958 he was appointed Director of Components Development with responsibility for the development and design of passive components for Bell System use.

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He spent 40 months in the Army Signal Corps, serving as radio officer during World War II in both overseas theatres. From 1952 to 1959 he worked on semiconductor device development at Bell Telephone Laboratories and since 1959 has been Chief Engineer, Diode Development, at Motorola Semiconductor Products Division, Phoenix, Ariz.

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Books

High-Frequency Magnetic Materials—Their Characteristics and Principal Applications, by W. J. Polydoroff

Published (1960) by John Wiley and Sons, Inc., 440 Fourth Avenue, New York 16, N. Y. 215 pages +4 index pages +x pages. Illus. 6×9¼. $9.00.

The subject of high-frequency magnetic materials covers a wide variety of materials for a multiplicity of applications. Considerably more than the 215 pages in this book would be required to treat the complete subject with any degree of thoroughness. The author has elected to emphasize several particular applications and materials characteristics related thereto—namely, magnetic core inductors, variable inductors for permeability tuning, and ferromagnetic antennas—and to provide only a cursory treatment of other high-frequency magnetic applications and their respective materials requirements and characteristics.

Following a short first-chapter introduction, the remaining thirteen chapters can be considered either as materials oriented or application oriented. Chapters 2–8 are concerned primarily with materials, their properties, measurement techniques, and methods of preparation; and chapters nine through fourteen deal with the applications of high-frequency magnetic materials.

Materials covered include elemental iron prepared by various processes (carbonyl, electrolytic, hydrogen-reduced, etc.); alloys of iron with other metals such as nickel, aluminum, silicon, tin, and antimony; and ceramic ferrites of the spinel type like nickel zinc ferrite. No mention is made of other types of ferrites, *e.g.*, the oriented-plane hexagonal ferrite. Dense and powdered forms of most of the included categories of magnetic materials are discussed. The account of measurement techniques describes mainly the methods of measuring permeability and loss of high-frequency core materials.

The last seven chapters stress the applications of high-frequency magnetic materials in magnetic core inductors, variable inductors for permeability tuning, and ferromagnetic antennas. The author references and discusses several of his patents in these chapters. A unique case of permeability tuning that was considered involves tuning by using the incremental permeability. Here, an additional winding passing a direct current of controllable magnitude changes the inductance of the coil by superimposing on the core material a steady flux. The author believes that this method possesses great potential for nonmechanical and remote-control tuning of all kinds of radio equipment. He cites as the major obstacle to this method the attainment of a steady direct-current source, but this reviewer feels he does not give due consideration to the deleterious temperature coefficient effects of ferrite core materials if the technique is intended for military equipment and consumer products.

Cursory treatment is given to other high-frequency applications of magnetic materials in the final chapters. These include loaded dipole antennas, delay lines, pulse transformers, memory cores, and microwave ferrites. Although one of the chapters is concerned totally with ferrites in microwave applications, the chapter cannot be interpreted as other than a superficial treatment because of the vastness of this particular field. The microwave chapter does, however, provide the reader with an introductory concept of several microwave applications of ferrites.

In general, the book provides a valuable source of information on magnetic materials, including much tabular and graphical data, and will be particularly useful to the applications engineer designing and employing high-frequency circuit elements such as magnetic core coils, tuners, and antennas. Written with a maximum of practical description and a minimum of complex mathematics, the book has an easy-reading manner of presentation, making it also useful to the novice desirous of general knowledge in this field.

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Linear Circuits, Part 1: Time-Domain Analysis; Part 2: Frequency-Domain Analysis, by R. E. Scott

Published (1960) by Addison-Wesley Publishing Co., Inc., Reading, Mass. 897 pages +12 index pages +xx pages +bibliography by chapter +6 appendix pages +37 answers to exercises pages. Illus. 6×9¼. Each volume $6.75.

The purpose of this two-volume treatment of linear circuits is to provide depth in network theory in a beginning course with a minimal allotment of time. To this end, the author has directed himself with noteworthy perception, clarity, and enthusiasm. Many subjects rarely found in a first course are concerned.

In both volumes, each chapter contains a summary of the most significant results, references, and an abundance of well-selected problems.

Approximately the first half of Part 1, "Time Domain Analysis," is given to the topology of networks with the elements being limited to resistors. This approach allows study of more complex network configurations without the attendant complexities imposed by reactive elements. The mesh and node equations, network theorems, and four-terminal networks are all considered in this section. Further, the mesh and node equations are extended to cover networks containing ideal current and voltage sources. In view of the fine quality of presentation, it would have been well to extend the mesh equations to non-planar networks in order that the mesh set have the broad utility of the node set.

The second half of this volume introduces the differential equations of reactive networks and considers classical solutions of these equations.

In Part 2, transform domain techniques are considered. About one half the book is devoted to sinusoidal steady-state solutions, with the remainder being given to applications of Fourier Series and the Fourier, Sine, Cosine, and Laplace Transforms.

Even though individual preference might dictate some differences in emphasis and order of presentation, the reviewer feels that this work merits careful examination by all teachers of network theory.

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Principles of Feedback Control, by C. H. Wilts

Published (1961) by Addison-Wesley Publishing Co., Inc., Reading, Mass. 244 pages +3 index pages +x pages +17 appendix pages. Illus. 6½×9¼. $8.75.

To summarize this book in the fewest words: very good! As stated in the preface the book gives rigorous treatment to the primary analytical tools of the servo designer. These tools include the Bode, Nyquist and root locus methods.

The complex variable theory is given as the prime mathematical means, with the Laplace transform appearing only often enough to remind the reader of its existence. This makes the book, in this reviewer's opinion. This approach puts the three methods previously mentioned in their proper perspective as mathematical tools useful as guides during feedback design. This is in contrast to the usual presentations where the methods are presented as panaceas.

The development of the book is straightforward and precise. Having the proper definitions in the proper spots is a good feature.

It is not until Chapter 7 that the actual servo design is introduced. The first six chapters logically develop the tools. The book them proceeds through multiloop systems, closed loop response, transient response, and other selected topics. These topics are described by all three methods: Bode, Nyquist, and root locus.

Chapter 11–12 cover sampled-data and nonlinear systems. The Z-transform and the describing function are examined.

It is felt that this book would be of greatest use to those who have had some previous studies in complex variables, both analytically and graphically. In addition, a course in response of physical systems is helpful but not essential.

While no handbook, the book serves a good purpose in training the senior or graduate student and the practicing engineer. It is strongly recommended to those in the control business as well as those wishing to get into this field.

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Electronic Equipment Reliability, by G. W. A. Dummer and N. Griffin

Published (1961) by John Wiley and Sons, Inc., 440 Fourth Ave., New York 16, N. Y. 257 pages+4 index pages+xi pages+12 bibliography pages. Illus. 5¾×8¼. $7.50.

This book supplies an excellent introduction to the background of reliability engineering. This rapidly expanding field is loaded with numerous papers but is lacking many good sound texts. Here is a book which covers the many phases of reliability and should be helpful to all those persons presently involved in reliability problems.

If we divide reliability into three major phases: parts and materials, systems, and quality assurance, it should be noted that the book is oriented towards the first of the three. This is good, for it can arouse the designers who must understand the need for reliability. There are valuable descriptions of part failure modes. Environmental effects and part testing methods are treated very well also. The book is not as strong in the latter two areas but it is impossible to expect everything within one volume. However, the sections on reliability predictions and reliability design are brief but concise. Enough information is presented to instruct the designers in the preparation of predictions and redundancy analyses. The subject of quality assurance was not formally presented. Its theme is not a necessary part of this kind of text.

A very valuable section of this book concerned human engineering. This is a very important marriage—human engineering and reliability. The chapter presents a good bit of definite design practices which, if followed, should increase the reliability of equipment operation.

The most severe criticism of the book is its presentation of old data. Most of the referenced articles date to the 1950–1957 era. Reliability techniques and failure rates of parts have changed greatly since that time. However, in contrast to some of the outdated information there is some good data on late techniques such as wire wrap, and some good information concerning printed circuit boards. Another disappointing factor is the lack of transistor data. Evidently the author plans an additional volume to discuss the semiconductors. Many preferred tube circuits are presented. At this point the book digressed into a set of pseudo standards which the reviewer believes is out of order in a text of this type.

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Mathematical Handbook for Scientists and Engineers, by Granino A. Korn and Theresa M. Korn

Published (1961) by McGraw-Hill Book Co., Inc., 330 W. 42 St., New York 36, N. Y. 746 pages+29 index pages+xiv pages+bibliography and references by chapter+164 appendix pages+7 glossary pages. Illus. 6¼×9¼. $20.00.

This comprehensive volume represents the first really authoritative attempt to describe mathematical formalism of vital importance to scientists and engineers. By steering a middle course between the facts and formulas which are typical of handbook treatment and the ponderous development which characterizes treatises in special fields, the authors have succeeded in condensing various aspects of modern mathematics into a coherent format. It is truly a remarkable achievement.

In referring to specific chapters, the reader will be highly impressed by the fact that details, which can usually seem too numerous and hopelessly confusing, fall into place with proper emphasis. As a special feature, the authors have thoughtfully included, at the end of each chapter, a cross-reference on those topics which are closely related throughout the handbook. Further, each chapter is very well documented with references and bibliography, and is sufficient in itself.

Chapter 1 begins with algebraic concepts involving real and complex numbers and develops several methods for locating the roots of algebraic equations and for solving simultaneous algebraic equations. Chapter 2 considers the basic concepts of plane analytic geometry and relations involving various geometries. These principles are extended in Chapter 3 to include solid analytic geometry. In Chapter 4, functions of real variables and their representations are described and a thorough treatment of limits, differential calculus, integral calculus, and infinite series is included. Elliptic integrals, Lebesque-Stieltjes integrals, Weierstrass's approximation theorems, Fourier integrals, and Fourier transforms are also discussed. Chapter 5 deals with vector analysis. Representations of scalar and vector functions in terms of curvilinear coordinates are formulated in Chapter 6. This chapter also lists useful equations relating to a number of special orthogonal coordinate systems.

Functions of a complex variable, the Laplace transformation, and other integral transformations, as well as the Schwarz-Christoffel Transformation, are the main topics of Chapters 7 and 8. A striking treatment of ordinary differential equations in Chapter 9 is followed by the development of partial differential equation as part of Chapter 10. This latter chapter also delves deeply into the characteristics and boundary-value problems of hyperbolic, parabolic, and elliptic second-order equations. The use of integral-transform methods is also outlined.

Chapter 11 introduces the reader to methods of solving problems by maximization or minimization techniques involving functions of real variables, definite integrals, and differential equations. Foundations of modern algebra, notably, groups, rings, fields, vector spaces, linear algebras, and Boolean algebras, are summarized in Chapter 12. The content of Chapter 13 relates to matrix algebra and matrix calculus. Chapter 14 reviews the theory of vector spaces and linear transformations. Chapter 15 considers the solution of linear boundary-value problems and eigenvalue problems involving differential equations in addition to potential theory and conformal mapping.

Chapter 16 establishes the basic rules of tensor algebra and analysis as applied to the description of curved spaces and continuous fields in physics. Chapter 17 emphasizes the use of differential geometry in describing curves in Euclidean space. Chapter 18 treats probability theory and random processes, including special procedures for solving probability problems and examples of random processes. Statistical methods are lucidly covered in Chapter 19. A variety of numerical computation schemes are detailed in Chapter 20. The calculus of finite differences is also introduced and applied to deriving numerical solutions. Chapter 21, as the final chapter, summarizes the characteristics of special functions, such as transcendental, gamma, elliptic, cylinder, step, and symbolic impulse functions. Polynomials of the Bernoulli and orthogonal types are also discussed.

Formulas describing plane figures and solids, plane and spherical trigonometry, permutations and combinations, tables of Fourier expansions and Laplace-transform pairs, tables of indefinite and definite integrals, and numerical tables of various functions are respectively introduced in the appendixes.

All in all, this is a timely handbook, written by just the right authors, about a subject of fundamental value to anyone concerned with the exact physical sciences and their applications. It is first rate all the way through.

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1959 Digest of Literature on Dielectrics, Louis J. Frisco and Thomas D. Callinan, Eds.

Published (1960) by the National Academy of Sciences—National Research Council, 2101 Constitution Ave., Washington 25, D. C. 421 pages+xiv pages+bibliography by chapter+1 appendix page. 8½×11. $8.00.

Like its predecessors, this book contains summaries of progress during the year in the broad field of dielectrics. It is the result of the efforts of approximately 50 specialists, and includes material from almost every subdivision of the field. Material is organized into chapters, in which easily-read, concise commentaries of notable results published during 1959 are given. These are amply interspersed with over 2200 references to books, periodicals, and conference papers.

Of the twelve chapters, one is devoted to instrumentation and measurements, one to applications of dielectrics, and the remaining ten to the theory and properties of materials. In addition to coverage of solid, liquid and gaseous conventional dielectrics, the digest includes material on photoconduction and electroluminescence. A large chapter is devoted to magnetic materials. Another covers ferroelectric and piezoelectric materials. Nineteen pages of tables of dielectric constants, dipole moments, and dielectric relaxation times are also included.

The depth of the material summarized makes this book of particular value to the research worker. The reviewer found several such people who were familiar with the volume to be unanimous in their expressions of its usefulness.

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The International Dictionary of Physics and Electronics, Second Edition, Walter C. Michels, Editor-in-Chief

Published (1961) by D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N. J. 1269 pages+85 index pages. Illus. 7⅛×10¼. $27.85.

This is a revised and up-dated edition, with a considerable number of new definitions added, particularly in such rapidly-growing fields as thermonuclear research, magnetohydrodynamics, nuclear physics, astrophysics and electronics. It encompasses over 8000 entries, and 300 illustrations and is amply supplied with mathematical expressions for important relationships.

This reviewer has checked a considerable number of entries, particularly in the solid-state and nuclear fields. Also, their conformance to some of the more recent IRE Standards was examined. In general this conformance is good; however, the editor has occasionally fallen into the common fault of revising some existing IRE definitions, possibly by changing only a word here or there. A more serious complaint is that in those IRE definitions which have notes included, these notes have been incorporated into the body of the definition without differentiation. In the proper usage, the notes are intended to be explanatory and do not form part of the actual definition and have no legal standing.

The coverage of the solid-state art is quite inclusive, particularly with respect to transistors. Tunnel diodes, however, were apparently not on the scene at the time of preparation, and are not included. Tunneling and the tunnel effects are, however, defined by reference to penetration probability. Similarly the epitaxial technique is not included directly, although there is a definition of epitaxy which is applicable.

There are some inconsistencies in the use of transistor letter symbols, as, for example, in the occasional use of lower-case subscripts for dc values, even though the section on transistor symbols itself is correct in most places. A few random items in this particular field: avalanche transistor is defined as being another name for a semiconductor controlled rectifier; drift mobility definition is quite different from current IRE definition; impurity definitions are radically different from the 1960 IRE Standard, and slightly different from previous 1954 Standard; and "hole" definition is radically different from IRE.

Coverage in the nuclear field is considerably less comprehensive than in the solid-state field. This reviewer looked in vain for a mathematical treatment of the fission process comparable to that given some of the mathematical concepts (*e.g.*, Elliptic Integral) or physical concepts (*e.g.*, Beta Decay Theory). Various reactivity terms are missing; precursor is mentioned but not defined; the definition of proportional counter reads like the IRE definition of Proportional Counter Tube but omits the "tube"; the definition of proportional counter tube refers to counter tube, proportional, but this is not listed; resolving time is not defined.

A few more items: emitance is defined as impedance and/or admittance, which does not conform to the IRE definition; transmittance is defined only for optics; transfer admittance is not defined as per the latest IRE Standard; "flip-flop" is indicated as being applied to monostable as well as to bistable multivibrators, which is not common practice.

This reviewer appreciates only too well how easy it is to pick out a few examples of errors or inconsistencies out of more than 8000 items and does not intend to imply that the work is, therefore, incorrect. Even where the definitions do not quote IRE exactly, they are usually clear and correct as to content; however, it should be understood that this is a glossary of terms, not a compilation of official definitions. If used in this manner this book will provide the user with an invaluable source of information and will be an indispensable item on many bookshelves.

The introduction is particularly valuable in providing an excellent chronology to the past two centuries' outstanding discoveries in the physical and chemical fields. One feature of particular value is the use of bold type to indicate items which appear in the dictionary proper. This device also serves nicely as a means of locating a particular item in this chronology.

The French-English, German-English, Russian-English and Spanish-English indexes are invaluable, not only as a means of providing cross-references between the various languages involved, but also as a pocket version of the usually much more comprehensive, hence larger, foreign langauage dictionaries. This can assist anyone with a moderate familiarity with the language to do a reasonable job of translating a technical paper.

In summary, "The International Dictionary of Physics and Electronics" is an excellent compilation of those terms likely to be of most interest to the engineer or physicist who wishes to become more familiar with the other's domain and to keep abreast of progress in his own, provided he uses it for what it is—a dictionary, not a standard.

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Design Fundamentals of Analog Computer Components, by R. M. Howe

Published (1961) by D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N. J. 261 pages+7 index pages+x pages. Illus. 6×9¼. $7.50.

The author of this volume is writing for those who already have an acquaintance with the modern electronic differential analyzer, and at least a general knowledge of its theory of operation is assumed.

The title is somewhat misleading in that it may appeal only to those who are engaged in the production of analog computer coponents, and not those who operate and maintain them. Such is not the case, and the author makes this clear in his introduction, where he explains why design details are important to the user of the computer. He states " . . . a complete understanding of the capabilities of an electronic analog computer cannot be obtained without considerable knowledge of the component details and how they affect the computer solutions." Thus, the general theme of the book (seven chapters, 261 pages) deals with the inherent imperfections in the electromechanical and electronic devices which comprise the modern analog computer.

Although it would be impossible to produce a book which is completely up to date in the computing field, especially when dealing with new equipment, the author has discussed more thoroughly than is elsewhere available the most common, off-the-shelf components of the several analog computer manufacturers. In particular, the author treats with the design philosophy of Electronic Associates, Inc., Beckman/Berkeley, Reeves and Goodyear Aircraft, the producers of the "PACE," "EASE," "REAC," and "GEAD," respectively.

Over-all system convenience is investigated with respect to patchboard systems, set-up and control methods and problem check circuits. Detailed circuits are given and analyzed for the most common computing elements. Particular emphasis is given to the effect of nonlinearities, finite band-pass, phase shift characteristics and their effects upon problem solution. Specifically, the elements discussed are: dc amplifiers; servo, electronic and diode square law multipliers; function generators; recorders; noise generators and time delay units.

Since ultimately the accuracy of analog simulation must be referred to the operating characteristics of the individual computer components, this volume should prove of considerable value to those who operate and maintain analog computers.

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Solid State Physics in Electronics and Telecommunications, Vol. 2. Semiconductors, Part II, M. Désirant and J. L. Michiels, Eds.

Published (1960) by Academic Press, Inc., 111 Fifth Ave., New York 3, N. Y., 645 pages+xvii pages+bibliography by chapter. Illus. 6¼×10. Chapters in English, French, and German. $18.00.

This book constitutes the second volume of the *Proceedings of the International Conference on Solid State Physics in Electronics and Telecommunications* held in Brussels (June 2–7, 1958), and sponsored by the International Union of Pure and Applied Physics. The first volume deals with preparation and properties of semiconductors (the principal emphasis being placed on germanium and silicon), solid-state theory, effects of intense electric fields in semiconductors, noise, and surface phenomena. Volume 2 contains 72 papers, the papers being printed in the respective languages of presentation at the Conference. (Forty-one papers are written in English, and the remainder in German and French.)

A major portion of Volume 2 deals with semiconductor compounds (33 papers), their physics, preparation and properties, such as electric, magnetic, Hall-effect, optical, magnetoresistive, thermoelectric, magneto-thermoelectric, electroluminescent, photoconductive, and photoelectric properties. A few papers treat thin film compounds. A second, relatively brief, section (6 papers) deals with a few, apparently somewhat erratically-se-

lected, semiconductor applications. A third, also major, portion of the volume (27 papers) presents papers on semiconductor devices, their properties and methods of fabrication. Discussed are diodes, transistors (including power transistors and avalanche transistors), 4-layer devices, field effect transistors, microwave diodes (including parametric and breakdown types), double base diodes, and other special devices. The fourth section of the book (6 papers) is devoted to semiconductor power rectifiers.

The book contains a great deal of most valuable material and can, in many respects, serve as a useful reference source for people active in the semiconductor field. However, considering that the papers were published in 1958 and that, therefore, much of the knowledge described in the papers was gained in 1956 or so, large portions of the volume can be considered today as outdated or superseded by more recent information. Nevertheless, this reviewer still recommends the volume as a very desirable component of a solid-state library.

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Semiconductor Abstracts, Vol. VI—1958 issue, J. J. Bulloff and C. S. Peet, Eds.

Published (1961) by John Wiley and Sons, Inc., 440 Fourth Ave., New York, 16, N. Y. 470 pages+57 index pages. 8½×11¼. $14.00.

Since its inception in 1953, "Semiconductor Abstracts" has been a valuable tool for both theorists and practitioners of the state-of-the-art in semiconductors. Furthermore, these abstracts have been available at a reasonable price. The sponsors are to be commended for continuing this series.

A review of this type appropriately is started by taking a look at the table of contents. Here we are able to see the changes that have been reflected in this year's issue of "Semiconductor Abstracts." More emphasis has been placed on the most popular semiconductor topics of the period. For example, Boron, which enjoyed a heading of its own in the 1957 Abstracts, is now found under "Other Inorganics." The work properly starts off with germanium and silicon, covers other elemental semiconductors, the Halides, and then a new grouping is cataloged, entitled "Chalcogenides," which is followed by the group III–V Intermetallics, Other Inorganics, and then Organics.

The next section is concerned with theory of semiconductors. This is followed by an application section, which more properly might be entitled "State-of-the-Art."

Now that we have covered the general organization of this year's "Semiconductor Abstracts," we find upon examining the abstracts in detail that they have improved over those of previous issues and that seldom does one read an abstract with the feeling that not enough information has been given to determine the content of the original paper. The only objectionable criticism that the reviewer can raise with this issue of "Semiconductor Abstracts" is that of incorrectly placing some abstracts. As a specific example, Abstract No. 1074 is entitled "Lifetime of Non-Equilibrium Charge Carriers in Germanium for Arbitrary Injection Levels." Upon reading the title, and further, the abstract itself, it is obvious that this abstract is concerned with semiconductor theory. Yet it has been placed in the section on "Other Inorganics."

In spite of this one basic criticism, the book is a worthwhile and necessary tool for theoretical, experimental, or state-of-the-art investigation into semiconductors.

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Field Theory for Engineers, by Parry Moon and Domina Eberle Spencer

Published (1961) by D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N. J. 515 pages+10 index pages+ix pages+4 appendix pages. Illus. 6¼×9¼. $12.75.

This is another addition to the growing volume of books on fields and waves written at the intermediate level. For the most part it deals with Laplace's equation and its solution by separation of variables. The merit of the book lies in the clear and well-illustrated treatment of a large number of boundary-value problems. In addition to covering the usual coordinate systems, the authors also describe bicylindrical, bispherical, and toroidal systems. Interesting applications are made to electromagnetic, acoustical, thermal and gravitational fields. The presentation requires only a rudimentary background in differential equations, vector analysis, and classical physics.

While the book is clearly written, the reader may be baffled at times by the notations. For example, a superscripted asterisk is not used to denote a complex conjugate, but rather, it indicates any complex quantity. Also, cylindrical Bessel functions are denoted by unfamiliar script letters.

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Terrain Scattering Properties for Sensor System Design (Terrain Handbook II), by R. L. Cosgriff, W. H. Peake, and R. C. Taylor

Published (1960) by the Engineering Experiment Station, College of Engineering, The Ohio State University, Columbus. 114 pages+vi pages+3 bibliography pages. Illus. 6×9. $3.00.

The scattering properties of terrain make up as confusing a subject matter as exists in physics. The current theoretical approach to the subject consists of a hodgepodge of "models," each of which depends upon a constant which must be evaluated experimentally for each terrain sample, and which still may or may not "fit." These difficulties arise because the theoretical basis being used is highly oversimplified, and the resulting short algebraic expressions are simply not adequate.

The reasons for these complications are manifold: first and foremost, both the transmitter and the receiver are in the near field; second, the roughness can usually be described only by statistical parameters; third, the terrain is far from a perfect conductor, and its electromagnetic constants vary considerably not only from place to place but also with the seasons of the year.

The idea that the power returned from rough terrain obeys an inverse R^3 law has been with us for some time.[1] Of course the usual (far zone) R-dependence in the radar range equation is R^4, but in the near zone it is R^2. Thus, for example, the radar cross section of a sphere of radius a when the wavelength is small with respect to a and the radar is in the far field is $\sigma=\pi a^2$; if the radar is in the near field and we define the radar cross section to apply to that case, then $\sigma=4\pi R^2$ where R is the range from the transmitter-receiver combination to the specular point on the sphere. Thus in the near field the return is independent of the radius of the sphere to the first order (as long as the principal radii of curvature are large with respect to the wavelength). Physically this is to be expected, since when one is close to the surface of a sphere, locally the sphere looks flat.

Now when we extend these concepts to cover areas which are "rough," the roughness parameters being of the order of, or larger than, the wavelength, and if we remain in the near zone, a combination of laws comes into play. The R-dependence changes due to the relation between the area and the range, the beamwidth, and the product of pulse length and velocity of propagation. These complications must be added to those due to near-zone effects, roughness, and imperfect and varying conductivity and permittivity.

These theoretical difficulties are not adequately faced in the handbook under review. For example, the subject of relationship between scattering properties of a surface and its apparent temperature and applications of the theory, including some experimental results, are all covered in eleven pages. In fact, the theoretical portions would have been better eliminated from this handbook, as it is felt that they do not do justice to the field. To those readers who are interested in understanding models of roughness, the handbook is not considered an adequate source of reference material and is not recommended.

On the other hand, this handbook gives an excellent experimental summary of the present state of terrain scattering technology and is quite valuable for this purpose alone. There is a rather good bibliography, which is reasonably representative as far as experimental work is concerned. But, especially if pertinent theoretical papers were to be included, it would be easy to triple the number of references to U. S. literature and, what is most unfortunate, the key references for the U.S.S.R. are missing.

To summarize this reviewer's opinion: this book is recommended to those who want a quick reference on experimental data on terrain scattering. To those desirous of understanding the theoretical models of terrain scattering, or deriving their own models, this handbook is not recommended as a reference source.

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[1] L. N. Ridenour, "Radar System Engineering," McGraw-Hill Book Co., Inc., New York, N. Y., p. 86; 1947.

Linear Graphs and Electrical Networks, by Sundaram Seshu and Myril B. Reed

Published (1961) by Addison-Wesley Publishing Co., Inc., Reading, Mass. 292 pages+5 index pages+x pages+10 bibliography pages+8 appendix pages. Illus. 6¼×9¼. $9.75.

As stated by the authors, the aim of "Linear Graphs and Electrical Networks" is "to provide, for electrical engineers, an introduction to the theory of linear graphs and to demonstrate the power of these methods in solving network problems." This aim is sufficiently well achieved that the reviewer intends to devote substantial effort to intensive study of some of its chapters. The book is organized along lines of definition, theorem statement and proof, and illustration. While the book is short, only 292 pages, its information density is very high. It will challenge most readers, and at the same time will be rewarding in the sense of extension of the reader's mathematical horizons.

The basic theory of linear graphs is developed in the first five chapters of the book, which account for about one-third of its length. Linear graph theory is a branch of mathematical topology, so it should not be surprising that these five chapters depend heavily upon matrix theory and modern algebra. A background of matrix theory is presupposed. On the other hand, little acquaintance with modern algebra is assumed; hence concepts such as number fields, Boolean Rings, and Abelian Groups are introduced, defined, and illustrated as needed.

The remaining chapters, five in number, are devoted to applications of graph theory. Chapters 6–8 are concerned with graph theory formulations of Kirchhoff's Laws, of energy functions and stability, and of topological considerations of linear networks. Chapter 9 will be of special interest to engineers who are interested in switching theory. Topics such as contact networks, sequential machines, and logic networks are considered. The communications specialist will find an area of interest in Chapter 10, which consists of a brief survey of the applications of graph theory to various types of communications problems.

In the opinion of this reviewer, this is an excellent book. It is worthy of study by network theorists, switching theorists, and communications specialists.

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Physics of Semiconductors, by A. F. Ioffe

Published (1961) by Academic Press, Inc., 111 Fifth Ave., New York 3, N. Y. 432 pages+4 index pages+xi pages+bibliography by chapter. Illus. 6¼×9¼. $12.50.

Professor Ioffe's text, "Physics of Semiconductors," is written from the viewpoint of an experimental physicist. The concepts and mechanisms are developed intuitively with analytical formulations presented in a style which should be appealing to the experimentalist.

The first chapter deals with solid electrolytes and is both historical and introductory in character. The nature of ion and electron currents and their statistical behavior in various solid electrolytes are discussed and the groundwork laid for interpreting some of the phenomena observed in semiconductors which cannot be treated classically.

Chapter 2 contains a brief but concise treatment of the electrical and thermal properties of metals. The presentation is made in the language and pictures of Sommerfeld's theory neglecting the effects of periodic potential variations in the lattice.

Chapter 3 is a general survey of semiconductors containing a phenomenological description of the more important effects found in semiconductors with elementary explanations of the mechanisms. At this stage the only aspect of quantum mechanics employed has been the use of Fermi-Dirac statistics for electrons.

Chapter 4 introduces the modern Quantum Theory of Semiconductors. Here we find a discussion of energy bands; their population; a quantum mechanical treatment of the motion of free electrons and electrons in a periodic field; the concept of effective mass; holes; impurity levels; polarons; excitons; and a critical review of the present state of semiconductor theory.

Chapter 5 is probably the most important section of the text. This chapter, entitled "Physical Phenomena in Semiconductors," discusses crystal properties influencing the more useful semiconductor functions; the nature and influence of imperfections and impurities in the crystal lattice; phonon and electron propagation, scattering, mean free path and mobility; surface states; contact resistance; rectification of barrier layers and junctions; transistors; photoelectric and photovoltaic effects; contact potentials; thermionic and secondary emission phenomena; effects of applied electric and magnetic fields on semiconductors; magnetoresistance; paramagnetism; cyclotron resonance ferro- and antiferromagnetism. In addition to all of these phenomena, this section contains an interesting discussion of thermal conductivity in semiconductors, and under a section on thermoelectricity is a summary of most of the information contained in the author's well-known monograph on "Semiconductor Thermoelements and Thermoelectric Cooling."

Chapter 6 reviews methods which have been developed for measuring the basic properties of semiconductors, including: electrical conductivity, electron and hole mobilities; electron and hole concentrations; band gaps; lifetime and diffusion length; Seebeck coefficient; thermal conductivity; specific heat; velocity of sound; contact potential; Hall coefficient; dielectric constant; magnetic susceptibility

Chapter 7 contains a summary of known properties of a wide variety of semiconducting materials.

The book contains a final chapter entitled, "Conclusions," in which Ioffe has written a beautiful analysis of the advances which have been made and limitations which remain in developing a completely satisfying theory to explain the phenomena observed in semiconductors.

This book possesses the charm and appeal which most frequently occur when an author writes in an area in which he has, himself, made significant contributions. It contains a summary and digestion of much work which has been published in Russia and is relatively inaccessible outside of Russia.

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Recent Books

Cahen, Gilbert, and Treille, Pierre, *Nuclear Engineering*. Allyn and Bacon, Inc., College Div., 150 Tremont St., Boston 11, Mass. $8.50.

Elsevier's Dictionary of Automation, Computers, Control, and Measuring. Compiled and arranged on an English alphabetical base by W. E. Clason. Elsevier Publishing Co., Amsterdam, Netherlands. $27.50. (English language distributor: D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N. J.) In English, Dutch, French, German, Italian, and Spanish.

Murphy, Glenn, *Elements of Nuclear Engineering*. John Wiley and Sons, Inc., 440 Park Avenue South, New York 16, N. Y. $7.50. Presents, at the college level, a survey of the field of nuclear engineering for the purpose of indicating its scope, potentialities, and limitations.

NMR and EPR Spectroscopy. Pergamon Press, Inc., 122 E. 55 St., New York 22, N. Y. $12.00. Papers presented at Varian Associates' Third Annual Workshop on Nuclear Magnetic and Resonance and Electron Paramagnetic Resonance, Palo Alto, Calif.

Pickard, J. K., Warren, F. H., Lowe, W. W., and McLain, S., *Power Reactor Technology*. D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N. J. $11.25. The Second Geneva Series on the Peaceful Uses of Atomic Energy. Evaluates efforts toward goal of economic nuclear power, with pertinent operating results and technical and economic data for further development.

Savant, C. J., Jr., Howard R. C., Solloway, C. B., and Savant, C. A., *Principles of Inertial Guidance*. McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, 36, N. Y. $9.75. Covers basic concepts of navigation and elements required for automatic navigation; discusses the autonavigation components and computers, platform controllers, ground alignment, and pre-flight testing; and presents theoretical information on inertial navigation principles.

Stout, M. B., *Basic Electrical Measurements, Second Edition*. Prentice-Hall, Inc., Englewood Cliffs, N. J. $11.65. Revision of the original textbook in which Chapter 2 ("Experiments and Statistical Analysis") has been considerably lengthened and updated. Elements discussed are basic passive measuring devices; the more refined and specialized devices using active circuits are not treated.

Scanning the Transactions

A new method of guided propagtion of electromagnetic wave beams has been proposed which has important application to the transmission of millimeter waves. The new technique makes use of the fact that a wave beam emitted by a highly directional antenna has within the Fresnal region a substantially uniform diameter. If a way could be found to form new Fresnal regions exactly like the original at uniform intervals along the beam path, the beam would then pass along with essentially no change in diameter and with little loss. The key ingredient which made this idea workable was the discovery that the cross-sectional amplitude distribution of the beam repeated itself at a certain distance from the origin. Therefore, if the original phase distribution could be made to repeat itself at that point, too, the requirements for forming a new Fresnal region identical to the original would be met. This was accomplished by inserting at that point of the beam a phase transformer, in the form of a dielectric lens, which reconstituted the original phase distribution in the required manner. The result was an open waveguide consisting simply of a series of dielectric lenses spaced at uniform intervals along the beam path. A beam waveguide of this type, consisting of a row of dielectric lenses 20 cm in diameter and spaced one meter apart, was built and tested at 23 kMc, with excellent results. In addition to low loss, an interesting property of the beam waveguide is that it can turn corners easily without introducing any distortions or additional losses because the beam can be deflected by means of reflectors or dielectric wedges. (G. Goubau and F. Schwering, "On the guided propagation of electromagnetic wave beams," and J. R. Christian and G. Goubau, "Experimental studies on a beam waveguide for millimeter waves," IRE TRANS. ON ANTENNAS AND PROPAGATION, May, 1961.)

Management and information theory, two unlikely bedfellows, have been tentatively coupled in an interesting compatibility test to determine whether information theory might be applied to the study of real management situations. Specifically, it was desired to know whether information theory concepts would be at all useful in 1) analyzing the communication system within an enterprise that uses electronic data processing or other automation methods, 2) forecasting demands or other economic factors, and 3) studying production processes. The study was made not without some trepidation. Information theory analogs have been used—perhaps overused—in a wide variety of far removed fields. The question of whether such analogs lead to useful results or practical benefits is a controversial one. The present study was, therefore, noteworthy in two respects. First, it was concluded that information theory was *not* generally useful in situations 1) and 2) above. Secondly, it was concluded that the most promising application of information theory to management control appears to be in viewing the production process as the adding of information to raw materials in order, for example, to measure work in progress in a convenient way. Whether this approach bears fruit must await further studies. Should it prove to yield new insight into management operations, especially those that are not already intuitively understood and practiced, further progress will have been made in formalizing the art of management. (R. C. Hopkins, "Possible applications of information theory to management control," IRE TRANS. ON ENGINEERING MANAGEMENT, March, 1961.)

Land's two-color projection system has been a widely discussed subject during the past two years. Following Land's original demonstration others have conducted similar experiments in an effort to determine whether two-color projection could give as good results as conventional tricolor projection. It was found that generally the quality of two-color pictures was inferior. However, the quality of a picture is a matter of subjective judgment. Since there was a considerable lack of statistical data on this question a further study was recently conducted, using students at the Swiss Federal Institute of Technology as subjects. The results showed that the students judged the two-color pictures inferior to the tricolor pictures. It was also found that in viewing two-color pictures the mechanism of color transformation worked well with most persons when viewing natural scenes, but seemed to fail when looking at abstract pictures. An interesting detail of the results is that a minority of students could detect little or no difference between the two forms of projection. While the results apply only to the particular two-color system used in the experiment, it was concluded that it is improbable that sometime a two-color process might be found which will give the spectator the same quality reproduction as tricolor projection. (C. Burckhardt and M. J. O. Strutt, "Experiments with E. H. Land's two-color projection," IRE TRANS. ON BROADCAST AND TELEVISION RECEIVERS, April, 1961.)

The Citizens Radio Service is experiencing an astounding boom which in the last two years has made it second only to the Amateur Radio Service in the number of licensed stations. Indeed, by the end of this year it will probably have passed the Amateur Service in numbers. The Citizens Radio Service was first set up by the FCC at the end of World War II to make radio communication available to private individuals, and the 460–470 Mc band was allocated for this purpose. By 1958 a modest 36,000 licenses had been issued. By the end of 1960 the number had swelled to 150,000 and was growing at the rate of 10,000 a month. At least 60 manufacturers are now engaged in large scale production and sale of sets or kits of station equipment. The cause of this sudden boom was two actions taken by the FCC in 1958: 1) the more accessible eleven-meter amateur band (about 27 Mc) was turned over to the Citizens Radio Service and 2) a new and technically simpler class of station (class D) was authorized. Today, the average family can install a base station at home and a mobile set in the car for less than half the cost of a good television set. It is this type of base-to-mobile communication, for business as well as family purposes, that accounts for most of the users of the Citizens Band. Sets may be found in boats, airplanes, house trailers, farm tractors, delivery trucks and snow plows, bringing added convenience or important economies to private citizens and to business enterprises. The foresight of the FCC in investing a small portion of spectrum space 15 years ago for use by the general populace is now paying handsome dividends. (I. H. Loucks, "The Citizens Band boom," IRE TRANS. ON VEHICULAR COMMUNICATIONS, April, 1961.)

Abstracts of IRE Transactions

The following issues of TRANSACTIONS have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y., at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

Sponsoring Group	Publication	IRE Members	Libraries and Colleges	Non Members
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Antennas and Propagation

VOL. AP-9, NO. 3, MAY, 1961

John T. Bolljahn, 1918–1960—J. V. N. Granger (p. 234)

The John T. Bolljahn Memorial Award—(p. 235)

Synthesis of Modulated Corrugated Surface-Wave Structures—J. T. Bolljahn (p. 236)

An exact procedure for the design of a surface that will support a prescribed group of surface waves simultaneously is described. The surfaces resulting from the application of this procedure are found to be modulated (*i.e.*, to contain periodic waves in the direction of propagation) and to have surface impedance values that vary periodically in the direction of propagation. Finite-length surfaces of this type are hence reminiscent of Simon's "cigar antenna." Several surface designs are presented, and some general properties of the surfaces and the composite waves they support are discussed. Certain limitations on the design procedure are described.

Magneto-Ionic Faraday Rotation of the Radio Signals on 40 Mc from Satellite 1957α (Sputnik I)—E. V. Sørensen (p. 241)

Some of the fadings of the 40-Mc signals from Sputnik I during morning transits are assumed to originate in Faraday rotation in the ionosphere. This has been investigated for the transit of October 12, 1957, 5:30 GMT, for which the orbit was known with reasonable accuracy.

The fading records show an increasing fading rate during the last part of the transit. This is contrary to the simple theory based on the assumptions of a flat earth and a homogeneous ionosphere, from which a constant fading rate should be expected. The main reason why simple theory did not apply in this case is that the satellite travels through the twilight zone from night towards day, *i.e.*, from low to high ionization.

The Faraday rotation is calculated by means of data for the orbit, magnetic field maps and predictions of the ionosphere conditions. The result is in good agreement with the observation when a high ionization between the altitude of maximum ionization and the satellite is assumed. The effect of refraction is estimated by means of the perturbation theory. It increases the Faraday rotation from 0 to 19 per cent during the transit. The general conclusion is that, even though the fading behavior of a transit near sunrise is explainable to some extent, it is still difficult to deduce detailed information on the state of the ionosphere from it, especially when the frequency is so low that refraction becomes significant.

On the Guided Propagation of Electromagnetic Wave Beams—G. Goubau and F. Schwering (p. 248)

Any field in a half-space can be described by a continuous spectrum of cylindrical waves. If this spectrum comprises substantially only waves whose propagation constant is very close to the plane wave propagation constant, the field can be resolved into a set of elementary wave beams which are characterized by Laguerre polynomials. They satisfy orthogonality relations like the wave modes in a waveguide. The elementary beams or "beam modes" can be reiterated and guided by reconstituting the cross-sectional phase distribution at certain intervals. Reiterative beams are utilized in the beam waveguide. The finite size of the phase resetting devices effects a modification of the reiterative beam modes and causes diffraction losses. These losses decrease very rapidly with increasing diameter of the phasing devices.

Experimental Studies on a Beam Waveguide for Millimeter Waves—J. R. Christian and G. Goubau (p. 256)

The beam waveguide utilizes reiterative wave beams which are guided by resetting the cross-sectional phase distributions at periodic intervals. The major purpose of the measurements was to obtain data concerning the inherent losses of the guide, including the diffraction loss, caused by energy by-passing the phase transformers, and the dielectric and reflection losses of the phase transformers. Resonance measurements with an "open cavity," consisting of a section of a beam waveguide terminated by plane reflector walls, yielded the over-all losses of the phase transformers. In order to isolate the diffraction loss, pulse measurements were made between two reflectors, slightly curved to reset the phase distribution in the reflected beam. These measurements also gave information of the build-up of the reiterative wave beam. The experimental data support the theory which predicts that the diffraction losses of reiterative beams can be made extremely small.

Parasitic Excitation of Circular Antenna Arrays—T. L. Simpson and J. D. Tillman (p. 263)

A method of calculating the radiation pattern of a circular antenna array of parallel monopoles or dipoles using symmetrical components is presented. The results obtained when only one element of the array is excited are not particularly good. However, if an additional element is added at the center of the array a fairly good directional pattern results. The sidelobe level is dependent upon the tuning of this central element, and a graphical analysis is given which optimizes this tuning. Calculated and measured patterns are shown and compared. Sidelobe levels of 15 db, and a beamwidth of 78° are typical. The principal advantage of this antenna lies in the fact that the pointing of the beam can be changed by simply changing the element that is excited.

Angular Accuracy of a Phased Array Radar—L. E. Brennan (p. 268)

One type of phased-array radar of current interest employs an array of separate receiving elements, each followed by an individual amplifier. These individual signals are combined coherently to form one or more receiving beams for searching, tracking, or performing both functions simultaneously. This paper presents an approach to the theory of angle measurement with a phased array of this type.

In the one-dimensional problem considered here, the receiving antenna consists of a linear array of individual antenna-amplifier elements. The receiver-noise-limited case is considered, in which accuracy is limited by the additive normally distributed noise present in each channel. An expression is derived for the limiting accuracy of angular measurement when a single set of samples is available. This set of samples is obtained simultaneously, one sample from each channel. Next, two methods of implementing the angular measurements are discussed. These are amplitude comparison monopulse and a coherent or phase comparison technique. For large signal-to-noise ratios and for either a square law or a linear envelope detector, the accuracy of amplitude comparison monopulse approaches the theoretical limit. The same accuracy can be achieved with the coherent technique by proper weighting of the individual signals.

A Spiral-Doublet Scanning Array—John R. Donnellan (p. 276)

An array of eight spiral doublets, each doublet consisting of a pair of equally-excited two-wire spirals in the same plane and wound in opposite senses, has been used to scan a beam of horizontal polarization over a $\pm 40°$ range simply by rotations of the spiral doublets. The combination of a microstrip ring network and twin lead provided a balanced feed for each spiral in the array. Sidelobe levels were those

predicted (25 db) for the broadside pattern and at the test frequency of 1430 Mc—were, in general, below 19 db over the 80° scan. A novel microstrip feed harness provided isolation between the doublets and served to absorb most circulating currents. This printed circuit feedboard consisted of judiciously-grouped microstrip ring networks and provided the desired feeding coefficients to within ±0.1 db. An application of the array for tracking purposes is also described.

Leaky Wave Antennas II: Circular Waveguides—L. O. Goldstone and A. A. Oliner (p. 280)

The propagation characteristics of leaky waves on slotted circular cylinders are derived by the methods described in an earlier paper on leaky rectangular waveguides. The cross section of a typical leaky circular waveguide is represented by a radial transmission line network incorporating a lumped terminating admittance which characterizes the slot discontinuity and the external region. The expression for the lumped admittance is obtained by combining an integral equation solution with a variational procedure. The resonances of this transverse network, which yield the complex propagation constants for the leaky waves, are solved by perturbation techniques to produce results in simple and practical form. Solutions are obtained for leaky waves corresponding to two different excitations of a slotted cylinder and these results are shown to compare favorably with measured values.

A Spiral-Grating Array—J. R. Donnellan and R. T. Close (p. 291)

A problem associated with a two-dimensional spiral doublet array is concerned with the fact that use of the spiral doublet as an element to obtain linear polarization leads to spacing difficulties, since the distance between elements is always twice as much in one dimension as in the other. Thus, the allowable scan is seriously limited in one principal plane. A method is proposed for obtaining linear polarization from a *single* spiral antenna by using it in combination with a polarization grating and a ground plane. Experimental results were obtained by combining eight of these elements in a one-dimensional array. For the broadside position of the main beam, the field was found to be linear, with the cross-polarized component of the main beam being 40 db down from the principal polarization. As the beam was scanned out to ±45°, the linearity decreased quite rapidly (to approximately 10 db at 45°) and the plane of the linear polarization was rotated; sidelobes were higher than predicted. Use of this array rather than an array of doublets would involve a compromise concerning specifications, dependent upon the particular application of the array.

Coupled Surface Waves and Broadside Arrays of End-Fire Antennas—J. L. Yen (p. 296)

The concept of coupled surface waves is introduced to describe the action of element interaction in a broadside array of traveling-wave end-fire antennas. These coupled waves are formulated in terms of an interaction matrix, whose elements either can be determined experimentally, or, for some antenna structures, can be computed. Two methods of pattern evaluation based on two well-known approaches to end-fire antennas are then presented. The roles of interaction in the two methods turn out to be quite different, and the method which assumes radiation at the end of the antenna appears to be more favorable. A criterion on the over-all interaction effect on array pattern is introduced which indicates under what condition coupling can be neglected. Finally, the nature of patterns obtainable with different element spacings is examined.

Communications (p. 312)
Contributors (p. 321)

Bio-Medical Electronics

Vol. BME-8, No. 2, April, 1961

Montreal Symposium on Instrumentation Methods of Analysis, June 1–3, 1960:
Editorial—J. F. Davis (p. 82)
Random Selection System for Automatic Biochemical Analysis—Partial Functional Analysis—R. Jonnard (p. 83)

Interconvertibility of certain engineering units and time-motion studies leads to simplifications in simulating the chemist's performance. The system described utilizes a carrier stream into which samples and reagents are injected at controlled intervals. Reactions proceed in transit. Normalization results in replacing volume measurements by time, durations by distances and concentrations by rates of mass flow. Thus, all variables are controllable by means of timers.

The system incorporates a plurality of special plug-in units (pumps, mixers, sampler). Each operating module includes a multi-cam timer programmer. The modules may be arranged in series-parallel arrays. The system is pulse-operated from a random-access keyboard, so that a time-sharing programming method is possible. Setting of the measuring devices (colorimeter, pH-meter, etc.) for sensitivity, scale span and wavelength is automatic. A unique amplifier is utilized. Data logging is conventional. Performance analysis by application of the Sampling Theorem is useful in optimizing the operations. Examples dealing with urine color, albumin, glucose and nonglucose reducers by the peroxidase method, blood RBC and hemoglobin are described.

Application of Continuous Automatic Colorimetry in Medical Research—Jacques M. Kelly (p.98)

A recent development of interest in analytical instrumentation provides a system for the continuous automatic determination of a wide variety of biochemically important compounds by colorimetry. The system is controlled by a multichannel, peristaltic proportioning pump which accurately delivers fixed volume ratios of samples and reagents to other components. Purification or separation of the constituent to be analyzed is effected by continuous dialysis and, after appropriate chemical treatment, optical density is measured in a ratio-recording dual beam colorimeter fitted with a flow curette. The system can analyze different samples on a continuous basis or monitor changes in a continuous sample stream. Operations require a minimum of technical attendance.

The system has application in many areas of medical research: routine determination of classical clinical constituents for diagnosis and treatment; study of chemical pharmacology *in vivo* and *in vitro;* biochemical aspects of proteins, amino acids, and enzymes; organ and tissue perusal studies in physiology; microbial metabolism and assay; screening of experimental pharmacodynamic agents.

The design and operation of the instrument system will be treated in general terms and the application and results in the aforementioned fields of research will be discussed. Economies time and financial expenditure will be summarily noted.

Measurement of the Dielectric Properties of Blood—A. G. Mungall, D. Morris, and W. S. Martin (p. 109)

A capacitance-resistance bridge for the measurement of the dielectric properties of human blood at 100 kc is described. The use of inductively coupled ratio arms in the bridge greatly reduces the effect of stray impedances to ground. This allows the glass measuring cell to be mounted in a transparent plastic thermostatting box, without metallic shielding. Thus, the physical condition of the blood can be observed throughout the period of coagulation.

Observed changes in the capacitance and resistance of blood sample during coagulation are briefly outlined, particularly the effects observed when the blood samples are taken from donors who are known to have abnormal blood states.

Automatic Prothrombin Instrument—H. C. Ehrmantraut and B. D. Marshall (p. 111)

Various efforts to instrument coagulation determinations have proved either excessively costly or practically difficult. An instrument is described which is compact, reasonable in cost, and affords accurate, reproducible, nonsubjective determinations. Operation depends upon rotational sweep of precisely sized and located wires through the reaction mixture. Initial polymerization products are carried by one wire to a precision electrode arrangement which causes a sensitive electronic circuit to stop a timer. "Zero time" is automatically synchronized with the start of the reaction. A selector switch permits electrical adaptation of the electrode arrangement to determination of whole-blood clotting time. Extensive testing of a prototype instrument, confirmed by preliminary results obtained by various laboratories, indicates attainable accuracies of 0.3-second standard deviation.

Cardiac Dye Injector Synchronizer—L. David Pengelly (p. 113)

In radiographic diagnosis of heart disease, it is necessary to synchronize accurately the injection of radio-opaque dye into the circulation with the diastolic portion of the cardiac cycle. Because of the high-energy electrostatic and electromagnetic fields associated with radiographic apparatus, it was decided to make a photosensitive transducer to be clamped on the ear lobe to give an electric signal proportional to the blood flow through the ear. This signal is electronically shaped and amplified, and used to trigger a variable delay timing circuit which then operates the injector.

Some Techniques in Polarography—L. Katz and E. D. Gagnon (p. 117)

The basic polarographic circuit and its accuracy are discussed. A bridge-type current amplifier, using one transistor, is presented as one solution to the problem of displaying the very small current flow in a polarographic circuit. A second solution, the insertion of a pH-millivoltmeter directly into the basic control circuit, is evaluated from the medical worker's viewpoint. Techniques and circuits employing four different types of pH-millivoltmeters are described. The direct application of a polarographic cell for continuous measurement of the oxygen partial pressure in the blood of a heart-lung machine is presented.

An Air-Damped Artificial Mastoid—Erwin Weiss (p. 122)

An air-damped artificial mastoid has been constructed to simulate the mechanical impedance of the human mastoid. The instrument is used to determine the force transmitted through the skull by bone vibrators used in clinical audiometers and bone-conduction-type hearing aids.

Estimation of Cardiac Output in Man Using an Ear Oximeter and Coomassie Blue Dye—P. Sekelj and M. McGregor (p. 127)

A method of measuring cardiac output from dye-dilution curves recorded by an ear oximeter is described. No sampling of blood is necessary to make the dye-dilution curves quantitative. The inaccuracies inherent in the "end-tail" method of calibration are thus avoided and the technical procedure greatly simplified.

Theoretical considerations, circuitry and calibration procedures are discussed.

Forty-one cardiac output estimations were made in 15 subjects. Coomassie blue was used as indicator. Comparison was made between the results obtained by the technique under study and by the end-tail venous method. Seven results had to be excluded from the com-

parison due to manifest inaccuracy of the reference method, which is inherently inaccurate. In spite of this, there was reasonably good agreement. The standard deviation of the differences between simultaneous values by both methods was 14.3 per cent.

Fifty-two dye-dilution curves were recorded in seventeen white subjects at rest and during steady-state exercise at loads up to 600 kilogram-meters per minute. Comparison was made between the cardiac output estimates obtained by the technique described and by the "arterial end-tail" method. The standard deviation of the differences between the simultaneous values from the two methods was 14.2 per cent.

The Transmission of Red and Infrared Light Through the Human Ear—N. M. Anderson, P. Sekelj, and M. McGregor (p. 134)

A study was performed of the light transmission characteristics of the compressed "bloodless" ear in 70 subjects of white, Indian and Negro stock.

It was found that in white children and adults of both sexes, the ratio of light transmission of the red filtered photocells to that transmitted to the infrared photocell was virtually constant when the ear was rendered bloodless by compression. The error introduced by assuming this ratio to be constant was no greater than the errors involved in making the measurement.

If the assumption were made that this ratio was the same in Indian and Negro subjects as it is in white subjects, the estimation of the ratio would be in error in the average Indian subject by approximately −3.38 per cent and in the average Negro subject by −4.73 per cent.

Contributions:

The Normal Fetal Electrocardiogram, with a Proposed System of Standardized Terminology -S. D. Larks and R. Abdul-Karim (p. 136)

A system of standard electrode and patient positions for fetal electrocardiography as suggested by an international *ad hoc* committee, is presented. The variation in the accuracy of the fetal ECG technique during gestation is shown and discussed. Existence of two peaks of high accuracy, at 22 weeks and at term, is shown. Normal values for the duration of the fetal QRS are shown to increase from 0.026 second at 20 weeks to 0.040 second at term. Normal values and ranges for fetal heart rates and the amplitudes of the fetal QRS are reported.

A Theoretical Basis for Determining Heart-Lead Relationships of the Equivalent Cardiac Multipole—D. A. Brody, J. C. Bradshaw, and J. W. Evans (p. 139)

During the past few years, it has been proposed that the electrical behavior of the heart be represented more precisely by the addition of multipolar current singularities to the equivalent cardiac dipole. In this report, we have explored the factors which determine the relationship of each such multipolar component to the various electrocardiographic lead connections. Specifically, we have been able to amplify and generalize the concept of the ideal electrocardiographic lead field by showing that the electrocardiographic contribution of a given multipole component is related solely to the lead-field component of identical degree and order. Thus, the McFee-Johnston proposal for resolving lead fields is reintroduced, and the heart-lead property of each component is particularized. Finally, some brief, speculative remarks are made concerning possible biomedical applications of the generalized lead-field concept.

An Amplitude Distribution Analyzer for Studying Brain Waves—Fred L. Alexander (p. 144)

An amplitude-distribution analyzer which estimates the probability-density and probability-distribution functions of brain wave forms is described. The circuit uses high-gain dc operational amplifiers as its basic component and is simple in design. The theoretical probability-density and probability-distribution functions for a sine wave, a triangle wave and a random signal are discussed and compared with the experimental results of the analyzer.

Tribute to Dr. W. R. G. Baker (p. 148)

Announcements (p. 149)

Broadcast and Television Receivers

Vol. BTR-7, No. 1, April, 1961

Professional Group on Broadcast and Television Receivers Administrative Committee—(p. 1)

Minutes of PGBTR Administrative Committee Meeting, March 22, 1961 (p. 2)

Chicago Spring Conference on Broadcast and Television Receivers Program (p. 4)

Stuart William Seeley, Winner of the Magellanic Premium (p. 6)

The Challenges of TV in Education—T. F. Jones, Jr. (p. 7)

The future excellence of our educational system will depend largely upon the extent to which the capabilities of modern technology are exploited. TV in particular promises to play an important role by solving many problems in elementary, secondary, and higher education. MPATI, a large scale educational experiment involving a TV transmitter in an aircraft, is beginning operations this spring.

Although TV is sufficiently developed to meet many important educational needs, the engineer is challenged to develop techniques and equipment which will meet a broader range of educational needs more effectively and efficiently.

The paper summarizes the problems, the present solutions involving TV, and the challenges which face television engineers to provide improvements and new capability.

TV is Feasible for Regular Graduate Courses—Wayne B. Smith (p. 12)

Horizontal Scan Non-Linearity in Television Receivers and the Saturable Reactor—H. W. Claypool (p. 14)

Subminiature Tubes for VHF-UHF—R. Gausman (p. 21)

Network Design Analysis for Stereo Discriminators—John P. Pietrolewicz (p. 26)

A Foster-Seeley discriminator is used to detect the FM or PM information in a stereo signal. It is desired to design the detector for optimum sensitivity and linearity without excessive sacrifice of gain in the last IF stage.

The complex expressions involved in the transfer function are translated into a single algebraic equation relating the location of the poles to the zero by way of the parameter C_{11}/C_{22}, the ratio of primary to secondary capacitance. The particular case of critical coupling is treated and the problem of locating the zero is graphically presented. The influence of primary and secondary Q and C ratios on zero location and input impedance is described; associated design curves are plotted.

The application of these equations and curves to detector design is made. When increased discriminator linearity is desired, the zero must be moved further toward the "imaginary" axis—with corresponding sacrifice of gain and additional burden on the cost of the transformer. A sample problem is outlined in which bandwidth and zero location are chosen and the circuit parameters and input impedance are to be determined.

Experiments with E. H. Land's Two-Color Projection—C. Burckhardt and M. J. O. Strutt (p. 34)

Since the quality of E. H. Land's two-color pictures has been subject to discussion, two groups of students were asked to judge the quality of Land's pictures. The preparation of the slides and the experimental setup is described. The results show the inferiority of E. H. Land's system in its actual form to ordinary tricolor projection. From the results it appears that the mechanism of color transformation works well with most people tested, but that the lack of information contained in the slide photographed through the blue filter is considered serious. An interesting detail is that a minority of people can detect very little or no d fference between the two forms of projection.

Electron Devices

Vol. ED-8, No. 2, March, 1961

Some Properties of Multiple BWO's—E. A. Ash, L. Solymar, and A. C. Studd (p. 99)

Some of the fundamental properties of multiple BWO's are examined in terms of a simple model. The starting conditions are found for both low and high space-charge conditions and particularly for the case in which there is a small difference between the velocities of the separate beams. The latter results are used to discuss the tolerances which must be met in multiple BWO's. Experiments carried out at X band provide some qualitative confirmation of the theory.

Parametric Amplifier Using a Silver Bonded Diode—S. Kita, T. Okajima, and M. Chung (p. 105)

Recently, the parametric amplifier has merited attention because of its low-noise characteristics. A novel diode has been designed which is suitable for use in a parametric amplifier. The diode is a bonded type and is composed of a silver-gallium whisker and an N-type germanium. The cutoff frequency of the silver bonded diode is higher than 150 kMc. The parametric amplifier was made using these diodes at 6 kMc and 11 kMc, and stable gain of more than 20 db was obtained. The noise figures were approximately 5 db and 6.5 db at 6 kMc and 11 kMc, respectively.

Highly Linear Amplification with Transistors—N. E. Chasek (p. 110)

Highly linear amplification can be obtained with HF diffused-base transistors in the common base configuration. It is the purpose of this paper to 1) present experimental results to demonstrate this, 2) demonstrate the causes for this high degree of linearity and derive expressions for optimum bias voltages and currents (these results can be extended with certain restrictions to the common emitter and common collector configurations), and 3) present a general method for analytically treating nonlinearity in all transistor configurations.

A push-pull amplifier using 2N509- or 2N1195-type transistors provided 13 db of gain, with signal-to-distortion ratios of 70 to 80 db for broad-band white noise signals with +3 dbm of average output power or sine wave signals with +15-dbm peak output power. The stability of this gain and linearity with temperature and interchange of transistors is high. This high degree of linearity is shown to be due to 1) cancellation of current sensitivity nonlinearity in the emitter and collector resistances, 2) collector voltage bias adjusted so that the derivative of the collector conductance with respect to collector voltage is zero, and 3) the use of a high alpha cutoff frequency transistor. An expression derived for optimum bias was in good agreement with experiment. The nonlinear distortion in transistors is shown to be different from that found in most devices, in that there are frequency-sensitive and frequency-insensitive nonlinearities. A general

analysis carried out including these terms was in good qualitative agreement with experiment.

Simulating Parametric Amplifiers—William T. Hatley, Jr. (p. 116)

In this paper, the problems of producing a general simulator model of a parametric amplifier are discussed. This model is to be simple, accurate, and applicable to many forms of parametric amplifiers. A brief discussion of the theory behind parametric amplification is followed by proposals for three models. Each of these is discussed in terms of its limitations and applications. The results of tests on two of these models are presented, and these results are discussed. Some emphasis is placed on the most successful of the models, which has been used to simulate a subharmonic oscillator.

The Reverse Transient Behavior of Semiconductor Junction Diodes—W. H. Ko (p. 123)

The reverse transient behavior of junction diodes after a rectangular pulse of forward current is analyzed and the results verified experimentally. Based on the simplified planar diode model and the diffusion equation, equations are obtained to determine the reverse recovery current and voltage as functions of carrier lifetime and circuit parameters.

The transient behavior of both the open circuit and the closed circuit conditions are shown to be described by some set of equations, and the presently unrelated explanations are unified. The relation between the charge stored by forward current and the charge recovered by reverse current is then derived. These equations are confirmed with an accuracy of 5 per cent or better by experimental data from germinium and silicon alloyed diodes.

Several applications on measurements of diode material properties and on circuit applications (diode amplifiers, modulators, etc.) are suggested.

The Reflex Klystron as a Microwave Detector—B. G. Whitford (p. 131)

The mechanism of detection in a passive reflex klystron is discussed qualitatively on the basis of elementary space-charge theory with emphasis on the character of the anode-repeller potential distribution necessary for detection. Tabulation of tangential sensitivities obtained using several different tube types is included, together with other experimental data. It is shown that there is a possibility of using reflex klystrons as tunable detectors at frequencies where crystal diode performance is relatively poor.

Response of a *P-N* Junction to a Linearly Decreasing Current—M. A. Melehy and W. Shockley (p. 135)

A study is made to determine analytically the time variation of the terminal voltage of a *p-n* junction in response to a terminal current which starts with a large forward value and continues to decrease linearly until the reverse saturation is attained. It is shown that the period between the reversal of current and the reversal of voltage depends exclusively on the lifetime, diffusion length, and thermal equilibrium densities of minority carriers in both regions of the junction. For some cases, the period between the reversal of current and voltage reduces to half the lifetime of either of the two types of minority carriers. This property allows measuring the lifetime of minority carriers for certain *p-n* junctions by relatively simple means.

Tangential Magnetic Field Immersion of a Hollow Beam Electron Gun—E. J. Cook (p. 140)

Harris flow is one of a number of equilibrium electron beams requiring a launching method which imparts angular momentum to the stream. Immersion of the electron gun region in a magnetic field tangent to the cathode and orthogonal to the electron trajectories provides a means of rotation free of the defocusing and discontinuity effects of previous methods. Centrifugal-force spreading is eliminated by electric-field compensation in the gun. This compensation results in field lines at an angle to the stream edges and necessitates gun electrode design by a curvilinear flow method.

An immersed gun of this kind has produced a stable Harris flow beam containing 86 per cent of the total energy in rotational motion. Anode transmission is in excess of 95 per cent.

An Anomalous Flicker Effect in Tubes with Oxide-Coated Cathodes—R. C. Schwantes and A. van der Ziel (p. 150)

An anomalous flicker effect is observed in tubes with oxide-coated cathodes if the grid bias is near zero volts. The time constant deduced from the noise spectrum is of the order of 10^{-2} second. The magnitude of the noise increases strongly with increasing temperature. It is impossible to detect individual noise pulses. It is proposed that the noise is caused by individual positive ions emitted by the cathode and trapped in the space charge. The effect is similar to the anomalous flicker effect in tubes with tungsten cathodes; it differs in the time constant (10^{-2} second instead of 10^{-4} second) and in the magnitude of the ion pulses causing the effect (single ions or small numbers of ions instead of about 10^4 ions per pulse).

Charge Analysis of Transistor Operation Including Delay Effects—A. N. Baker and W. G. May (p. 152)

The charge control concept of transistor operation is extended to include delay effects in an accurate, yet tractable, way. Defining the transit time τ_t as the ratio of the excess base charge to the collector current, the transform of the transit time $\tau_t(s)$ is approximated by $\tau_t(1+s\tau_D)$, where τ_D is the delay time. For a one-dimensional, homogeneous-base transistor, $\tau_D=\tau_t/6$. The results of this technique are in good agreement with exact calculations.

Transfluxor Design Considerations—Walter L. Morgan (p. 155)

The transfluxor is a new magnetic device for use in information handling and nondestructive storage systems. The location and sizes of each of the several apertures determine many of the operating characteristics of the device. This paper discusses the various geometric and magnetic factors that should be considered before deciding upon a core configuration. Two methods, one based on a graphical approach, the other on mathematics, are outlined to determine the optimum shape for a particular application. A procedure may be reversed to predict the performance of existing cores. The flux storage principles are described and the equation $\phi_s=kI_c-k'$ is derived. This equation shows the relationship between the input current I_c and the stored flux ϕ_s. k and k' are design constants depending on the magnetic and physical properties of a core. Comparisons are made between a 346-mil (OD) core and one of 83 mils. Estimates are given as to the practical limits to which core miniaturization may be carried using existing fabrication methods.

A Unidirectional Amplifier with Esaki Diodes—W. J. Grubbs (p. 163)

Two Esaki diodes can furnish unidirectional amplification when used in conjunction with a Hall-effect isolator. The input and output impedances of this amplifier are greater than the absolute value of the negative resistance of the diodes by a factor which is proportional to the voltage gain. The voltage gain-bandwidth product of such an amplifier is $g_T/4\pi RC$, where g_T is determined by the isolator and RC is the usual RC time constant of the Esaki diodes. Typically g_T is between 0.1 and 1. If one of the diodes is removed, the remaining network still amplifies unilaterally, but the impedance at the diode-less end drops to that of the isolator alone. In addition, a Hall-effect gyrator or circulator can be made essentially lossless by the addition of Esaki diodes.

Experimental Notes and Techniques (p. 170)

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Program of 1960 Electron Devices Meeting (p. 174)

Engineering Management

Vol. EM-8, No. 1, March, 1961

About This Issue (p. 1)

The Study Committee for Research, Development and Engineering (SCARDE): A Progress Report and an Invitation to Participate—Peter V. Norden (p. 3)

Readers are invited to participate in a data-collection effort, conducted by SCARDE (Study Committee for the Analysis of Research, Development, and Engineering) on the patterns of man-power and money utilization currently found in R and D projects. The aggregated and summarized data should provide valuable insights into current practices in a variety of industries and firms of different sizes, and be useful to researchers interested in a quantitative approach to the management of R and D activities. Strict procedures to safeguard proprietary information have been established. The background and results of a pilot study are indicated, and an example of the possible use of the study results is presented.

Social Change in Science and Engineering—Herbert A. Shepard (p. 11)

Scientists and technologists are in the midst of an enormous social experiment, involving the growth of many new skill groups and the undertaking of very large and complex R and D projects. The boundaries of the engineering profession and a philosophy of organizing complex projects are discussed. Some effects on engineering education are traced. Differences between engineers and scientists are examined in the context of the "research and development explosion." Traditional functional differences are being erased, but some differences in personal and social characteristics are described.

Research, Development and Production: Problems of Conflict and Cooperation—Tom Burns (p. 15)

Technological change creates strains within the structure of the firm because it causes shifts in the relative power and influence between groups. The arrival of new groups in an organization such as a research laboratory creates linguistic problems: the language of the laboratory is different from that of the design activity and still different from that of the shop. To bridge the linguistic gap, interpreter or liaison groups are formed. In establishing these groups, management attempts to accommodate organizational strains within the existing structure rather than re-organize to reflect the new technology.

This study is based on the experiences of twenty firms in England and Scotland.

Developing Systematic Procedures for Directing Research Programs—G. R. Gargiulo, J. Hannoch, D. B. Hertz, and T. Zang (p. 24)

One of the most important functions of research management is to establish objective criteria for measuring the progress and performance of the research effort. Another important aspect is to allocate resources to research projects in the "best" manner. Two systematic procedures were developed in a large research laboratory to assist management in these tasks. The first is a Data Presentation System which provides a means for recording and presenting the status, progress and plans

for the research laboratory in terms of the allocation of resources. The second is an Evaluation System which provides a means for evaluating the technical and economic elements relative to research projects.

Weapon System Phasing for Ready Forces—Herbert K. Weiss (p. 30)

A ready force is defined as one designed to have a decisive capability in a short war in which the decision is reached before reserves and production capability can supplement the forces existing at the time hostilities begin. It is assumed that annual expenditures to equip, train, maintain and operate the ready force are constant. Within this constraint, it is desired to attain maximum effectiveness by balancing quality against quantity of weapons. Maximum quantity of weapons would be attained by selecting one type, and producing this type indefinitely, in view of decreasing unit production costs with number produced. However, rapid advancement of the state-of-the-art creates weapon obsolescence and, periodically, old weapons must be phased out and new weapons phased in. Maximum quality can be attained at the expense of quantity by very small production runs with frequent introduction of new weapons. The optimum program of effective weapons in sufficient quantity represents a compromise between the two extremes.

A model incorporating the variables of production cost, number of weapons produced, operating cost, growth of the state-of-the-art, effectiveness and budgetary limits is developed for a very simple model of warfare, and the relations among the variables for maximum force effectiveness are determined.

Strategy in Research—Alternative Methods for Design of Experiments—D. S. McArthur (p. 34)

Several simulated research problems have been programmed for the IBM 704 computer. Six different empirical research strategies have also been programmed for the computer. The "research problems" are "solved" by the computer using one of the six strategies to learn which is best. The computer uses each research strategy on each problem several times to get a statistical evaluation of its effectiveness. The work is not complete as yet; however, it has already had an influence on the way we are tackling some of our research problems.

Possible Applications of Information Theory to Management Control—Robert C. Hopkins (p. 40)

Several areas of possible application of information theory are discussed: 1) communication in automation, 2) forecasting, and 3) production processes. In the production area, the following possible applications are examined: "reduction of uncertainty" in raw materials and information content of a design. An example is given for a milling machine operation.

Engineering Writing and Speech

Vol. EWS-4, No. 2, May, 1961

The Cover (p. 34)

Human Responses—A Vital Link in Communications Progress. Part II—Beverly Dudley (p. 35)

An interpretation of the communications process is given in terms of stimulus and response. Part I, published in the January, 1961, issue of these Transactions, deals with communications in the physical and behavioral sciences and with the nature of stimulus/sensation under various sensory conditions. Part II deals further with the basic processes of communication and cites an example of underwater communication between submarines.

How to Write Officialese—Brockway McMillan (p. 42)

This paper gives an up-to-date communication basis for the 1961 time frame.

Better Writing: New Answers for an Old Problem—John B. Bennett (p. 44)

Instruction in the mechanics (grammar, spelling, punctuation, and the like) is no key to improved engineering writing. The critical factors in such improvement are correctness, completeness, and comprehensibility. These subjects can be taught through the use of simple student exercises specially designed to permit controlled emphasis on, and objective evaluation of, correctness, completeness, and comprehensibility; the same exercises make it possible to judge student competence in handling the less important mechanics. This approach has been tested and can be widely applied to improve the quality of our engineering writing.

Apply Quality Control to Engineering Writing—Ronald S. Blicq (p. 47)

Quality control can be exercised over engineering writing in the same way that it is exercised over manufacturing and installation/maintenance programs. In the case of writing, however, the "inspector" is the technical editor or a supervisory engineer. His terms of reference are the engineering writing standards laid down in a standards handbook prepared by those responsible for the production of technical publications.

The proposed "quality-controlled" engineering writing program has two major advantages:

1) It is simple to implement since it follows comparable established engineering and quality-control practices, to which engineers are accustomed.
2) It is imposed from within the department directly concerned with engineering writing, and is thus entirely independent of outside control.

Taking the Splatter out of Your Technical Writing—John M. Carroll (p. 52)

Three major ills of engineering writing are use of cliches, round-about expressions, and long, unfamiliar words. Articles containing such words and phrases are lengthy and tiresome to read, and often have their basic meaning obscured. Cliches, round-about expressions, and long words may be likened to solder splatter in a hand-wired chassis. Splatter gives the job an unprofessional appearance and may interfere with circuit operation. This article identifies many of the more common splatter-expressions that creep into engineering writing. It is based on a six-month study during which words and phrases deleted from articles published in *Electronics* magazine were accumulated and tabulated.

Persuasion in Engineering Proposals—Robert B. MacAskill (p. 56)

This article suggests several important methods by which an engineer writer may enhance his proposal in the eyes of the reader and future customer. Consideration is also given to the attitude the writer must take in order to write the successful proposal. The writer must become aware of the elements of persuasion in writing.

Library and Laboratory: Partners in Research—Harold S. Sharp (p. 58)

Duplication of research effort can be prevented when a literature search is made before starting laboratory work. The role of the librarian in assisting the engineer-researcher is discussed, and the services which can be expected of the librarian are stated. This article discusses certain library tools and techniques for the engineer-researcher.

Book Reviews (p. 62)

The Authors (p. 63)

Information for Authors (Inside Back Cover)

Microwave Theory and Techniques

Vol. MTT-9, No. 3, May, 1961

Octave-Bandwidth UHF/*L*-Band Circulator—F. Arams, B. Kaplan, and B. Peyton (p. 212)

Test data are presented on two aluminum-substituted yttrium-iron-garnet (YIG) materials that have low-saturation magnetizations that permit the extension of ferrite devices well into the UHF/VHF region. In particular, one composition has a saturation magnetization of 300 gauss and a line width of 50 oersteds. Measurements are presented that compare the new materials with previously available higher-saturation magnetization materials.

A broad-band UHF/*L*-band four-port circulator that operates over a 2-to-1 frequency band has been developed, using this 300 gauss material. Insertion loss is 1 db or less from 665 to 1320 Mc (with constant magnetic field) and 0.5 db or less from 800 to 1150 Mc. A very compact and favorable circulator package design was obtained by using coaxial hybrids and dielectric-loaded strip transmission line. Data on the broad-band magic-tee used in the circulator are included. Isolator measurements down to 200 Mc are reported. Reverse-to-forward magnetic-loss ratios of 36 at 600 Mc and 12 at 300 Mc were obtained.

A Five-Port Matched Pseudo-Magic Tee—Akira Okaya (p. 216)

The five-port matched pseudo-magic tee consists of an input waveguide, two load arm waveguides which are coupled into the input waveguide with $+90°$ and $-90°$ phase shifts, respectively, and an output waveguide which is split into two load waveguides by a septum.

The improvements include a much broader matching and isolation bandwidth, higher isolation between arms, better matching into arms, and a variety of modifications for different applications.

These characteristics have been obtained by employing frequency-insensitive phase shifters. Hence, frequency coverage is mainly limited by mechanical asymmetry and the characteristics of the directional coupler in the magic tee.

While this type of hybrid junction is not a true magic tee because the loads arms are not used as the input arm, it does have several applications which an ordinary magic tee does not have.

X-, *K*-, and *M*-band models were examined experimentally, and highly sensitive and accurate impedance measurements were made.

Theory of Dielectric-Loaded and Tapered-Field Ferrite Devices—R. F. Soohoo (p. 220)

Loading a ferrite resonance isolator or differential phase shifter with a dielectric or biasing the ferrite with an inhomogeneous dc magnetic field are very useful ways of improving the performance of these ferrite devices. Whereas these methods are very commonly used in transverse-field ferrite devices, no extensive analytical treatment of the subject has appeared in the literature. It is the purpose of this paper to present a theoretical analysis of the problem, chiefly by means of combined boundary-value and perturbation-theory approach. It will be shown that dielectric-loading and tapered-field techniques increase the bandwidth of isolators and phase shifters, the isolation-to-insertion loss ratio of the former, and the phase shift of the latter.

Theory of TEM Diode Switching—Robert V. Garver (p. 224)

The theory of TEM diode switching is presented for the purpose of understanding and designing TEM microwave diode switches. A few experimental results are reported for the purpose of supporting the theory and demonstrating the exceptional bandwidth possible.

An analysis is given of the switching action of one and of two or more diodes as well as the

biasing of the center conductor of a TEM transmission line over broad-frequency bandwidths without interacting with the RF signal. The use of point-contact germanium, varactor, and gold-bonded germanium diodes for TEM switching is discussed. Some considerations of switching speed and maximum power-handling capacity are given.

A coaxial transmission line switch has been constructed in which two gold-bonded diodes provide 26-db or greater isolation and insertion loss ranging from 1.6 db to less than 1 db from 40 Mc to 4000 Mc. The addition of a bias lead should increase the insertion loss 0.4 db or less over the 100-to-1 bandwidth, the maximum increase being at the upper and lower bounds.

Measurement of Small Dielectric Losses in Material with a Large Dielectric Constant at Microwave Frequencies—R. O. Bell and G. Rupprecht (p. 239)

A method is described for measuring dielectric losses at microwave frequencies in materials with a large dielectric constant. By observing a dielectric resonance in a sufficiently large sample, the loss tangent of the material can be obtained. Results on $SrTiO_3$ single crystals at 20 kMc are presented.

On the Existence of Leaky Waves Due to a Line Source Above a Grounded Dielectric Slab—E. S. Cassedy and M. Cohn (p. 243)

The existence of a particular type of leaky wave is verified experimentally. The leaky wave considered is that due to an electric line source above a dielectric slab. Since such a leaky wave cannot exist by itself, it must be detected in the presence of the remainder of the continuous spectrum and often in the presence of a surface wave (or waves). This was done by probing the fields and observing an interference pattern between the leaky wave and the existing surface wave, as predicted by the theory. These results emphasize a need to take leaky waves into account in the design of surface wave components and antennas.

A Broad-Band Glass-to-Metal Coaxial Vacuum Seal—W. M. Nunn, Jr., and L. E. Paul (p. 248)

The design procedure for a broad-band glass-to-metal seal is described, and experimental results are presented for a structure examined over the frequency range of 100 to 11,000 Mc. The seal described is capable of operating at bakeout temperatures as high as 450°C, with higher temperatures being attainable by the use of other materials.

Magnetically-Tunable Microwave Filters Using Single-Crystal Yttrium-Iron-Garnet Resonators—Philip S. Carter, Jr. (p. 252)

A new type of magnetically-tunable band-pass microwave filter that makes use of ferrimagnetic resonance in single-crystal yttrium iron garnet is presented. The 3-db bandwidth can be adjusted from about 6 Mc to 100 Mc at *X* band, and the center frequency can be tuned over a wide range of frequencies, by means of a varying dc field. A theoretical analysis of the operation and behavior of this type of filter is presented. Descriptions of single-resonator and two-resonator filters which can be tuned over the *X*-band frequency range are given and experimental data are presented showing their tuning range, insertion loss, and bandwidth.

Correspondence (p. 261)
Contributors (p. 275)

Product Engineering and Production

Vol. PEP-5, No. 1, April, 1961

Call for Papers and Correspondence (p. 1)

Analytical Dollar Tradeoffs for Development of Electronic Equipment—David Ehrenpreis (p. 2)

This paper presents reasons for the importance of formal documented analytical calculations regarding tradeoff decisions in the design and evolution of electronic and electromechanical equipment.

This paper offers several quantitative tradeoff factors which convert equipment design parameters to equivalent dollar penalties and values.

Solid State Laminants—Barton L. Weller (p. 9)

The technology of producing smaller electronic systems is going in the direction of creating function within single units. Achieving the ultimate in size reduction can come from experience in manufacturing commercial capacitors of porcelain-silver, fused laminants. This means of generating system in solids is described and examples of different three-dimensional structures are shown.

New Method in Vibration, Shock, and Stress Analysis of Electronic Equipment—John J. Albanes (p. 19)

Audio Visual Instructions for Electronics Assembly—A. P. Kromer (p. 31)

Small Lot and Specialty Production Problems—Harold M. Wilson (p. 33)

Value Engineering in Practice—Marvin Kaplan (p. 36)

Trade-Off Considerations in Using Automatic Test Equipment—E. L. Roel (p. 39)

Transportation and Packaging Techniques to Improve Reliability—Anthony Rubertone (p. 45)

An outline is presented of probable environments to be expected in shipping electronic equipment by the following:

1. Aircraft transport vehicles
2. Railroad
3. Trucks
4. Ships

The environmental engineering data are based upon previous studies and military governing specifications. Orders of magnitude are given as yardsticks for shock design inputs in terms of G level shock pulses, pulse shapes, pulse durations, population of pulses and direction of pulses. Test procedures to simulate environment shocks are described. Accelerated life test philosophy is defined.

Similarly, orders of magnitude are given for low frequency vibration inputs as terms of cumulative cycles, frequencies, G levels and amplitude levels. Test procedures are briefly discussed.

Discussion is included regarding electronic equipment resistance to environmental transportation shock and vibration. References are cited for the performance of rigorous analyses for determination of natural frequency and transmissibility. Recommendations are made for qualitative evaluation of electronic equipment resistance in shipping environments.

Transmissibility across suspension system during shock and vibration excitation is discussed. Incompatibility between shock and vibration isolation is discussed.

Vehicular Communications

Vol. VC-10, No. 1, April, 1961

Personal Radio Systems and Applications—John F. Mitchell (p. 1)

This paper is a discussion of the system aspects of radio systems designed to use the new types of Personal Radio Equipments which have been, and are being, introduced to the market in increasing numbers and types. Several actual applications are discussed. These examples cover the two basic types of equipment now in use, which are two-way non-selective call units, and one-way selective calling paging units.

The basic capabilities of the personal equipment are examined insofar as they pertain to Personal Radio System Design. The limitation and advantage of this equipment as well as the new uses and applications of this equipment are treated.

The Citizens Band Boom—Ivan H. Loucks (p. 6)

A Two Way Dial Private Mobile System for Telephone Construction and Maintenance—R. L. Flaminio and W. H. Rice (p. 11)

The assignment of frequencies by the Federal Communications Commission in 1958 for use by the Telephone Industry opened the way for obtaining more efficient plant operations through vehicular communications. The mobile communication system described in this paper was designed to serve the needs of the construction and maintenance forces in the Southwest District of the Bell Telephone Company of Pennsylvania.

The system employs decentralized dispatching which permits the supervisory personnel to use the service directly from their respective job locations. This is accomplished by incorporating the talking and signaling functions of the radio system into the standard Bell System 500 type telephone set normally used for the wire line service.

Since the dispatch points are located in administrative offices where loudspeaker operation must be avoided, mobile to base station dial signaling is employed. Similarly, dial signaling from base to mobile was used to protect the public from indiscriminate loudspeaker operation. Arrangements are also provided for mobile to mobile calls on a dialing basis. This feature is of significant value to the foremen who supervise a number of cable or line crews throughout a relatively large area.

Personal Radio Antennas—N. H. Shepherd and W. G. Chaney (p. 23)

The trend toward personalizing vehicular radio sets has been accompanied by major engineering problems. Of these, one of the most challenging is that of designing an efficient antenna to occupy a small space. Due to these size limitations, personal radio antennas will be referred to as small antennas.

This paper will describe a series of tests made under laboratory conditions followed by a coverage study made under service conditions in city streets to evaluate the relative performance of small antennas and accumulate propagation data for system design.

The laboratory measurements included a study of the properties of ferrite loop antennas, coils, whips and short wire antennas. The field measurements covered actual recorded field strength data from personal carried transmitters using reference quarter-wave whips.

It was concluded that $\frac{1}{4}$-wave whips even when working against as poor a ground plane as the set chassis offered the best performance. However, the 20 to 25 db of shadow loss found in city streets plus a 10 to 15 db antenna loss even with whips will severely restrict the coverage of personal transmitters. Other steps may be necessary if adequate areas are to be reliably covered.

Mechanical Filters for FM Mobile Applications—R. A. Johnson (p. 32)

The Western Division of Collins Radio Company has developed an electromechanical band-pass filter for use in the low frequency IF of split channel FM mobile receivers.

The "Mobile" Filter has a 455 kc center frequency and nominal 3 db and 60 db bandwidths of 13 kc and 28 kc respectively. The filter is fixed tuned, enclosed in a third of a cubic inch package and was engineered with the idea of low price without compromise in performance.

The Mobile Filter gives both the equipment designer and user excellent selectivity and stability, so essential when operating under split channel conditions, along with a flat amplitude response and low loss.

A Modular Approach to the Design of FM Communication Equipment—B. Tennent and G. G. Armitage (p. 38)

Through the use of coils wound on subminiature ferrite bobbins, threaded ferrite cup cores and of newly released P.A.D.T. transistors, the IF strips of an FM communications receiver have been packaged into two compact, hermetically sealed, pre-tuned components. This ensures built-in optimum performance, reliability and standardization of an important section of FM receivers for all frequency ranges and simplified maintenance.

Similar developments for other sections of FM communications equipment and for Citizen's Band Radio are referred to in this paper.

A Selective Ringing Decoder for Mobile Radiotelephone Use—James D. Malone (p. 49)

A Centralized Mobile Telephone Test Panel—John P. Gill (p. 55)

A centralized method of testing Mobile, Test and Base Station Transmitters "Off the Air" has always been considered desirable. With the inauguration of 450 Mc narrowband common carrier telephone service with its more stringent requirements, a centralized method of testing has become almost a necessity.

The Centralized Mobile Telephone Test Panel described herein can be used to evaluate the over-all performance of the Mobile telephone system and can also be used as a tool to insure proper routine operation of a system. Provisions are made in the CMTTP for automatic sampling of each radio channel with statistical evaluation of ON-OFF frequency operation of mobile transmitters.

The present unit is arranged to monitor on the 450 Mc and Personal Signaling (Bellboy) services only. However, the test panel can be readily adapted for the 40 and 150 Mc channels as well.

Control Consoles—The VHF Integrators—Hugh H. Davids (p. 64)

Control circuitry integrates pieces of communication equipment into VHF communication systems. The control functions for simpler systems are adequately provided by standard remote control units, using options to provide for a variety of needs.

More complex systems require special control circuitry and control consoles whose design is part of the overall system design. A duplex backbone system such as used on cross-state turnpikes is typical of such complex systems. Party line vs multi-channel design of such systems is contrasted and use of various devices such as receiver voting discussed.

Console design is illustrated by discussing features of the Massachusetts Turnpike Control Console. Range of control design is indicated by mention of two-way mobile telephone requirements and the potential field of remote control from portable control consoles, such as remote control of a switching locomotive.

A Proposed System for 11 Channel Access in the Mobile Telephone Service—C. A. Rypinski, Jr. (p. 75)

A signaling, supervision and radio technique suitable for multi-channel access in the VHF MTS band is proposed. The logic is based on the continued use of 600/1500 cps transitional signaling and certain existing methods of transmitting supervisory signals to the base terminal. Mobile identification is provided but is neither required or excluded. The availability of a mobile radio equipment which does not deteriorate as a result of continuous channel switching is assumed.

Signaling tone at either frequency is used to mark the idle channel on which the next call will appear or on which the mobile may seize the terminal. If the mobile is not locked on a channel marked idle, the busy indication is given.

The logic of this technique is further detailed in a table and is illustrated by tracing sequences of calls including special cases such as carrier fade, simultaneous seizure and the persistent caller with no answer.

To illustrate feasibility a suitable mobile decoder and control unit is described which provides decoding, supervision and logical control. Component content of this design is tabulated.

A possible configuration of a preferred mobile radio transceiver is proposed which employs synthesis type channel switching, linear detection and full duplex operation. The 13 crystals employed are shared by transmitter and receiver and only one is a high accuracy type.

It is the object of this paper to encourage the adoption of a multi-channel access standard to serve the interval preceding the development of the broad-band service by showing compatibility with existing technique and the feasibility of the required equipment.

The Use of Level Controlling Devices in the Radio-Telephone Service—L. E. Getgen (p. 87)

This paper introduces the subject of speech level control as applied to radio-telephone service by presenting statistical data describing talker level variations and anticipated levels at the telephone central office. Because speech measurements are difficult to make, mention is made of speech to sine wave relationships that are convenient for system line-up. Next, maximum levels are established for the output of the controller and application to the wire-line or the radio transmitter.

The operational characteristics of three available types of level controlling devices are discussed. These are: the Agamp and Vogad which were designed specifically for control of speech levels into radio transmitters; the clipper-limiter commonly used in radio broadcasting; and the Compandor which is familiar in telephone applications.

Recordings were made of these devices in operation. Analysis of these recordings as related to the "ground rules" established in the text allowed conclusions to be drawn concerning the most advantageous use of each.

In discussing the use of level controlling devices, it is necessary to determine the nature of the signals that are to be controlled. Where telephone facilities are to be used, consideration must be given to plant practices. These practices as well as the transmitter input requirements will establish the output level limits for the device. Having an idea of the input and output requirements and taking into account unusual noise and environmental conditions, the next step is to examine the characteristics, and cost, of available units to determine the extent to which they meet the system application.

Measurement of Deviation and Frequency in FM Two-Way Radio Systems—M. Cooper (p. 98)

Sinad System Design—R. A. Farmer (p. 103)

This paper deals with performance parameters used in designing a communication system, black boxes and all, rather than with the circuit parameters needed to design the individual equipments which make up the total system. There is a common language for use in the Land Mobile Services which should, but does not yet, have the stature of CCIF and CCITT specifications used by system designers in the field of point-to-point communications. The Electronic Industries Association (EIA) specifications for Land Mobile equipment are examined and their applicability to system design work is discussed.

Abstracts and References

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research, London, England, and Published by Arrangement with that Department and the *Electronic Technology* (incorporating *Wireless Engineer* and *Electronic and Radio Engineer*) London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

Acoustics and Audio Frequencies..... 1246
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The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

UDC NUMBERS

Certain changes and extensions in UDC numbers, as published in PE Notes up to and including PE 666, will be introduced in this and subsequent issues. The main changes are:

Artificial satellites:	551.507.362.2	(PE 657)
Semiconductor devices:	621.382	(PE 657)
Velocity-control tubes, klystrons, etc.:	621.385.6	(PE 634)
Quality of received signal, propagation conditions, etc.:	621.391.8	(PE 651)
Color television:	621.397.132	(PE 650)

The "Extensions and Corrections to the UDC," Ser. 3, No. 6, August, 1959, contains details of PE Notes 598–658. This and other UDC publications, including individual PE Notes, are obtainable from The International Federation for Documentation, Willem Witsenplein 6, The Hague, Netherlands, or from The British Standards Institution, 2 Park Street, London, W.1, England.

ACOUSTICS AND AUDIO FREQUENCIES

534.2 1695

The Effective Dynamic Parameters for Sound Propagation in Inhomogeneous Media—I. A. Ratinskaya. (*Akust. Zh.*, vol. 6, no. 1, pp. 128–131; 1960.) A revision of an earlier analysis [1041 of 1959 (Kaĭkovich and Khalfin)] is given.

A list of organizations which have available English translations of Russian journals in the electronics and allied fields appears each June and December at the end of the Abstracts and References section.

The Index to the Abstracts and References published in the PROC. IRE from February, 1953 through January, 1960 is published by the PROC. IRE, June, 1960, Part II. It is also published by *Electronic Technology* (incorporating *Wireless Engineer* and *Electronic and Radio Engineer*) and included in the April, 1960 issue of that Journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

534.2–14 1696

Sound Field of a First-Order Normal-Mode Wave in a Layer of Water—F. I. Kryazhev. (*Akust. Zh.*, vol. 6, no. 1, pp. 65–76; 1960.)

534.2–14 1697

Normal-Mode Waves in a Three-Layer Medium—F. I. Kryazhev and N. A. Petrov. (*Akust. Zh.*, vol. 6, no. 2, pp. 229–236; 1960.) An analysis is given of experimental data on the propagation of sound waves in some shallow waters of the Caspian Sea in the frequency range 8–1000 cps. Waveguide-type propagation occurs at values of $kh > 2.8$, where k is the wave number and h the layer depth.

534.2–14 1698

A Method of Wave Front Determination for a Sound Wave of Approximately Sawtooth Form—L. K. Zarembo. (*Akust., Zh.*, vol. 6, no. 1, pp. 43–46; 1960.) An analysis of the propagation of sawthooth waves in water is given.

534.2–14 1699

Investigation of Low-Frequency Sound Propagation in Shallow Waters—V. S. Grigor'ev and F. I. Kryazhev. (*Akust. Zh.*, vol. 6, no. 1, pp. 34–42; 1960.) A description of an experimental method illustrating the waveguide-type propagation of sound in sea water at frequencies up to 10 kc is given.

534.213.4 1700

Sound Propagation in a Waveguide with Rectangular Grooves in the Walls—A. D. Lapin. (*Akust. Zh.*, vol. 6, no. 2, pp. 237–243; 1960.) A mathematical treatment relating to acoustic filters is given. The optimum size of a transverse channel in a waveguide wall for greatest sound reflection is determined and the frequency characteristics of a waveguide are obtained.

534.213.4–14 1701

Signal Amplitude and Phase Fluctuations Induced by Surface Waves in Ducted Sound Propagation—J. A. Scrimger. (*J. Acoust. Soc. Am.*, vol. 33, pp. 239–247; February, 1961. The dependence of the amount of amplitude and phase fluctuation in received signals on surface wave crest-to-trough height has been determined for frequencies in the range 1–10 kc propagated over a distance of 300 feet in water 10 feet deep.

534.213.4–8 1702

Theory of Ultrasonic Attenuation in Cylindrical and Rectangular Waveguides—E. F. Carome and J. M. Witting. (*J. Acoust. Soc. Am.*, vol. 33, pp. 187–197; February, 1961.) The systems studied consist of a piston source radiating into a bounded inviscid fluid and a receiver the same size as the source. Expressions for receiver output are derived, and acoustic loss as a function of path length is computed for various source and waveguide configurations.

534.22–8–14 1703

The Propagation Velocity of Ultrasonic Wave of Finite Amplitude in Liquids—L. K. Zarembo and V. V. Shklovskaya-Kordi. (*Akust. Zh.*, vol. 6, no. 1, pp. 47–51; 1960.) An application of a phase-comparison method for an investigation of velocity jump is given.

534.232 1704

Experimental Investigation of Cylindrical Focusing Systems—I. N. Kanevskiĭ. (*Akust. Zh.*, vol. 6, no. 1, pp. 123–124; 1960.) Results of measurements made on cylindrical $BaTiO_3$ focusing radiators in the frequency range 600–900 kc with angles of aperture 30°, 60° and 90° are noted.

534.26 1705

Diffraction of a Plane Sound Wave Incident at an Arbitrary Angle on an Infinite Cylindrical Cavity in an Elastic Medium—V. V. Tyutekin. (*Akust. Zh.*, vol. 6, no. 1, pp. 101–106; 1960.)

534.26–14 1706

Scattering of Acoustic Energy by Solid and Air-Filled Cylinders in Water—G. R. Barnard and C. M. McKinney. (*J. Acoust. Soc. Am.*, vol. 33, pp. 226–238; February, 1961.) Results are given of an experimental investigation of the scattering of acoustic energy from solid and hollow cylinders as a function of cylinder length, pulse length and frequency.

534.286–8 1707

Contribution to the Theory of Ultrasonic Absorption in Metals—V. P. Silin. (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 977–983; March, 1960.) A theoretical treatment of low-temperature absorption at wavelengths small compared to the electron mean free path is given. In the region of wavelengths which are approximately equal to the thickness of the anomalous skin layer a decrease in the ratio of the absorption coefficient to frequency should be observed with increase of frequency.

534.41:538.652 1708

The Relation between the Magnetic Properties and Sensitivity of Magnetostrictive Receivers of Nickel-Zinc Ferrite—A. D. Sokolov

and Ya. S. Shur. (*Akust. Zh.*, vol. 6, no. 1, pp. 131–133; 1960.) Experimental data are tabulated.

534.52 1709
Sound Field in the Focal Plane of Converging Spherical Beams—B. D. Tartakovskiĭ. (*Akust. Zh.*, vol. 6, no. 1, pp. 96–100; 1960.) The distribution of the oscillation velocity and sound pressure in the focal plane is calculated for a focusing system in which the beams have a nonuniform amplitude distribution over the wave front.

534.6:534.84 1710
Application of Frequency Modulation to Acoustic Measurements—V. A. Zverev and A. I. Kalachev. (*Akust. Zh.*, vol. 6, no. 2, pp. 205–212; 1960.) A CW FM technique is described for measurements in normal rooms. Spectrum and correlation analysis are applied for locating sources of sound and reflections. The autocorrelation process makes it possible to separate the discrete reflections from reverberation signals.

534.61–8:539.2 1711
Phonon-Photon Double-Quantum Transitions as a Detector of Microwave Ultrasonics—N. S. Shiren. (*Phys. Rev. Lett.*, vol. 6, pp. 168–170; February 15, 1961.) A fast intensity detector for microwave ultrasonic pulses is described. The spin systems of Ni^{2+} and Fe^{2+} in MgO crystals at 2°K are used. The absorption of CW microwaves is increased when ultrasonic pulses are transmitted through the crystal. Absolute ultrasonic energy measurements are possible.

534.75 1712
Subdivision of the Audible Frequency Range into Critical Bands (Frequenzgruppen)—E. Zwicker. (*J. Acoust. Soc. Am.*, vol. 33, p. 248; February, 1961.) A note showing the relation between critical-band function and frequency, and defining the proposed frequency limits of the critical bands is given.

534.79 1713
The Loudness of Directional Sound Fields—D. W. Robinson and L. S. Whittle. (*Acustica*, vol. 10, no. 2, pp. 74–80; 1960.) Subjective measurements have been made in the frequency range 1.6–10 kc of the variation of loudness with source direction, together with corresponding measurements of sound pressure. The loudness estimated from the sound pressures at left and right ears agrees well with the observed binaural loudness if a 6-db summation law is assumed.

534.844 1714
Recent Subjective Acoustic Investigations of Reverberation Time—T. Tarnóczy, T. Járfás, and M. Lukács. (*Elektron. Rundschau*, vol. 14, pp. 223–226; June, 1960.) A definition of "subjective reverberation time" is given which is based on a subjective assessment allowing for different musical tempi. Experimental results are discussed.

534.844.1+[621.317.2:538.566.08 1715
The Upper Limits for the Reverberation Time of Reverberation Chambers for Acoustic and Electromagnetic Waves—K. Walther. (*J. Acoust. Soc. Am.*, vol. 33, pp. 127–136; February, 1961.) "The upper limits for the reverberation time and Q factor of acoustic reverberation chambers with perfectly rigid walls with a smooth surface are determined. The reflection factor for a rigid wall of arbitrary thermal conductivity is determined from a consideration of the viscosity and heat conductivity-boundary layer. The cases of isothermal and adiabatic boundary conditions are discussed. See 1393 of May (Meyer, *et al.*).

534.844.1 1716
Measurement of the Degree of Diffusion of a Sound Field in Rooms by Means of a Directional Microphone—V. V. Furduev and Chen Tun. (*Akust. Zh.*, vol. 6, no. 1, pp. 107–115; 1960.) The method is based on a comparison of the directivity characteristics of a microphone in a "dead" room and in the room to be investigated. The theory of measurement using a microphone which is a combination of a pressure type and pressure-gradient type is given. Some results obtained in a reverberation chamber and broadcasting studios are shown.

621.395.61 1717
A Microphone Arrangement of High Directivity—P. Dämmig. (*Acustica*, vol. 10, no. 2, pp. 120–123; 1960. In German.) A parallel arrangement of two groups of slit-tube directional microphones forming a crossed array is described. The half-width of the directional characteristic is 15° at 1 kc and 12° at 4 kc.

621.395.616 1718
Pressure Response of Condenser Microphones at Low Ambient Pressures—J. D. Chalupnik, E. Rule, and F. J. Suellentrop. (*J. Acoust. Soc. Am.*, vol. 33, pp. 177–178; February, 1961.) Pressure response curves at a number of ambient pressures in the range $10^6 dyn/cm^2 - 17 \times 10^4$ dyn/cm² have been obtained for two commonly used condenser microphones. Features of the response curves are discussed from a qualitative point of view.

621.395.625.3:538.221 1719
The Properties of Modern Magnetic Recording Tapes—P. H. Werner and E. Kohler. (*Tech. Mitt. PTT*, vol. 38, pp. 217–228; July 1, 1960. In French and German.) Mechanical and electrical properties are reviewed and means of reducing print-through effects are discussed.

ANTENNAS AND TRANSMISSION LINES

621.315.212 1720
Continuous Loading of Coaxial Circuits without Air Gap—P. M. Prache. [*Câbles & Trans.* (*Paris*), vol. 14, pp. 180–190; July, 1960.] A theoretical determination of the attenuation in a coaxial circuit loaded by toroidal ferrite cores inserted between the two conductors so that there is no air gap is given. Experimental results confirm the theoretical calculations and show that it is possible to reduce coaxial-circuit attenuation in this way, at least for frequencies up to 2 Mc.

621.372.2:621.372.44 1721
Periodic Solutions of the Wave Equation with a Nonlinear Interface Condition—W. L. Miranker. (*IBM J. Res. & Dev.*, vol. 5, pp. 2–24; January, 1961.) An analysis is given of the voltage oscillations in a transmission line when shunted with a diode represented by a nonlinear capacitance.

621.372.8:621.396.44 1722
Characteristics of Waveguides for Long-Distance Transmission—A. E. Karbowiak and L. Solymar. (*J. Res. NBS*, vol. 65D, pp. 75–88; January/February, 1961.) A detailed discussion and analysis of propagation characteristics including effects of bends and other discontinuities are given. 35 references.

621.372.81 1723
The Theory of Waveguides and Cavities: Part 2—Examples of Waveguides and Discussion of Special Points—R. W. Waldron. (*Elektronic Tech.*, vol. 38, pp. 140–147; April, 1961.) The method described in Part 1 (1404 of May) is applied to two examples: a) an air-filled circular waveguide; b) a coaxial line in which the core material is considered as a dielectric.

4621.372.826 172
Sommerfeld and Harms-Goubau Waveguides in the Centimetre and Millimetre Wave Range—H. Severin. (*Arch. elekt. Übertragung*, vol. 14, pp. 155–162; April, 1960.) The calculation of transmission characteristics of surface waveguides for cm and mm λ is made. Curves are included of the radius of the external field and of attenuation as a function of frequency and line parameters. Given a maximum permissible attenuation of 3.5 db/km, Sommerfeld and Goubau lines are not suitable for wavelengths below 5 cm.

621.372.826:537.226 1725
Measurement of the Properties of Dielectric Transmission Lines at Millimetre Wavelengths in an Optically Coupled Resonator—G. Schulten. (*Arch. elekt. Übertragung*, vol. 14, pp. 163–166; April, 1960.) Measurements of dispersion and attenuation of the HE_{11} mode were made at 5 and 8 mm λ on threads of polythene of various diameters for use as dielectric lines of the ordinary or image type [see *e.g.*, 2827 of 1959 (Schlesinger and King)].

621.372.831.2 1726
The Reflection of the Fundamental Mode at Waveguide Discontinuities, particularly with a Gradual Transition from a Rectangular to a Circular Waveguide—K. Schnetzler. (*Arch. elekt. Übertragung*, vol. 14, pp. 177–182; April, 1960.) Theoretical expressions are derived for the reflection of the fundamental mode at waveguide junctions involving smooth transitions with small angles. Calculated values for a rectangular/circular junction agree well with measured values.

621.372.837 1727
A Low-Loss, Semiconductor Microwave Switch—D. L. Rebsch. (Proc. IRE, vol. 49, pp. 644–645; March, 1961.) The superiority of a new semiconductor switch configuration is discussed in which the diode is mounted in the arm of symmetry of an H-plane T-junction.

621.372.853.1 1728
Backward Waves in Waveguide with Anisotropic Dielectric—F. Borgnis. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1030–1033; October 8, 1960.) The conditions under which separately excited backward waves can exist in a waveguide are investigated.

621.372.853.2 1729
Backward Waves in Longitudinally Magnetized Ferrite Rods—A. W. Trivelpiece, A. Ignatius, and P. C. Holscher. (*J. Appl. Phys.*, vol. 32, pp. 259–267; February, 1961.) A quasi-static approximation $(\nabla \times \vec{H}) = 0$ is used to develop a theory of this effect, the waves propagating with a phase velocity $< c$ and in a frequency range where the permeability is negative. Experimental measurements of phase velocity are described. Interaction with an electron beam is considered.

621.396.67(24) 1730
Useful Radiation from an Underground Antenna—H. A. Wheeler. (*J. Res. NBS*, vol. 65D, pp. 89–91; January/February, 1961.) Radiation efficiency is derived simply for a) a vertical loop in a submerged radome, and b) a submerged horizontal insulated wire with each end connected to a ground electrode. A power efficiency of 0.0014 is given in a specific example of b).

621.396.674.3 1731
The Characteristics of Dipole Impedances with Dipole Excitation Varying Exponentially with Time—K. Fränz. (*Arch. elekt. Übertragung*, vol. 14, pp. 167–168; April, 1960.) A mathematical treatment of dipole impedance by variational principles for real frequencies > 0 is given.

621.396.677:523.164 1732
An Interferometer for the Measurement of Radio-Source Sizes—Goddard, Watkinson, and Mills. (See 1817.)

621.396.677:621.391.812.63 1733
Launching Over the Sea of Vertically Polarized Waves for Long-Distance Ionospheric Propagation—E. O. Willoughby. [*Proc. IRE, (Australia)*, vol. 21, pp. 591–597; September, 1960.] Simple vertically-polarized antennas from mast heights of 150 feet or less, launching over the sea, are shown to be capable of gains exceeding 14 db over a frequency band of 5 to 15 Mc, with good matching and efficient radiation between 1° and 10° elevation.

621.396.677.3 1734
Linear Aerial Arrays with Attenuated Side Lobes—K. Baur. (*Elektron. Rundschau*, vol. 14, pp. 217–222; June, 1960.) The radiation diagrams of linear antenna arrays are discussed and a method is given for modifying sidelobe maxima, and operating bandwidth and radiation angle by varying the antenna spacing. Examples of 4-, 8- and 16-antenna arrays with unequal antenna spacing are given.

621.396.677.3:621.396.965 1735
A High-Resolution Rapid-Scan Antenna—H. V. Cottony and A. C. Wilson. (*J. Res. NBS*, vol. 65D, pp. 101–110; January/February, 1961.) A description is given of an electronically-scanned broadside receiving array of 7 Yagi elements with spacing 1.4 λ. A 5.8° beam swept over a 41.8° azimuth 20 times per second is produced, operating at 40.92 Mc. Sample records showing ionospheric scatter and reflections from meteor trails and sporadic-E are given.

621.396.677.83:621.396.65 1736
The Deflector as Part of a Directional Aerial System—H. D. Kühne. (*Telefunken Ztg.*, vol. 33, pp. 120–131; June, 1960. English summary, pp. 157–158.) The design of plane or parabolic reflectors used as deflectors in radiolink antenna systems is described [see 45 of January (Münzer)]. Experimental results obtained at 3.3 and 7.5 cm λ are compared with calculated data.

AUTOMATIC COMPUTERS

681.142:538.221:539.23 1737
Patterns in Thin Films make Fast Nondestructive Memories—J. W. Hart. (*Electronics*, vol. 34, pp. 126–129; February 17, 1961.) The Kerr magneto-optic method is used to show that irreversible domains can be formed in thin magnetic films.

681.142:538.221:539.23 1738
The Problem of 'Coupling' in a Switching Circuit System consisting of Thin Magnetic Films—H. Oguey. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1004–1010; October 8, 1960.) Problems relating to the design of logic switching circuits formed by magnetic film elements are reviewed.

CIRCUITS AND CIRCUIT ELEMENTS

621.316.86:621.317.332 1739
The Impedance Value of Carbon Film Resistors as a Function of Frequency and D.C. Resistance—A. Debel and L. Hechler. (*Frequenz*, vol. 14, pp. 193–197; June, 1960.) An arrangement is described for impedance measurements in which the dimensions of the mounting are standardized in relation to resistor dimensions so that comparisons are possible between results obtained for resistors of different size. Curves are given of maximum usable frequency as a function of dc resistance, and of skin effect as a function of frequency and surface resistance.

621.318.57:621.382.33:517 1740
Methods of Analysis of Circuit Transient Performance—L. Hellerman and E. J. Skiko. (*IBM J. Res. & Dev.*, vol. 5, pp. 33–43; January, 1961.) A survey is given of some numerical methods for studying the performance parameters associated with transient behavior of switching circuits.

621.319.45 1741
Properties and Characteristics of Tantalum Capacitors with Solid Electrolyte—W. Ackmann. (*Nachrtech. Z.*, vol. 13, pp. 261–265; June, 1960.)

621.372:621.391.822:621.385.2 1742
Nonlinear Thermal Fluctuations in a Diode—N. G. Van Kampen. (*Physica*, vol. 26, pp. 585–604; August, 1960.) As an example of nonlinear noise, the fluctuations in a circuit consisting of a diode and a capacitor are studied and the complete fluctuation spectrum is calculated. See also 1898 of 1960 (Alkemade).

621.372.413 1743
Time Delay and Frequency Response of Resonant Cavities—A. G. Mungall and D. Morris. (*Canad. J. Phys.*, vol. 38, pp. 1510–1515; November, 1960.) "The frequency response and time delay characteristics of resonant cavities are discussed. It is found that a signal travelling through a resonant cavity undergoes a time delay dependent on both the cavity Q and also the difference between the signal and resonant frequencies. The time delay for a frequency-modulated wave is calculated and checked experimentally."

621.372.44:517.512.2 1744
Application of Distortion Functions to Instantaneous Nonlinear Circuits—R. Codelupi. (*Note Recensioni Notiz.*, vol. 9, pp. 489–540; May/June, 1960.) A mathematical treatment of nonlinear nonreactive networks using the functions derived in 3975 of 1960 is given.

621.372.5 1745
The Propagation Coefficient of a General Linear Quadripole—H. Weber. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 958–960; October 8, 1960.) Current and voltage relations in a quadripole joining two transmission lines are calculated using methods of image-parameter theory.

621.372.5.029.6 1746
Determination of the Characteristic Impedance of Any Quadripole at Microwave Frequencies—S. Lefeuvre. (*Comple rend. Acad. Sci., Paris*, vol. 250, pp. 3288–3289; May 16, 1960.) Measurements made on the quadripole under certain load conditions are used in determining the characteristic impedance by a graphical method.

621.372.54 1747
The Modification of Wide-Band Noise Phenomena by Linear Transmission Systems—H. Schlitt. (*Arch. elekt. Übertragung*, vol. 14, pp. 239–246; June, 1960.) For simple types of filters the distortion of the power spectrum and autocorrelation function is investigated with wide-band noise as input. Relations between parameters of classical and of statistical system theory are derived.

621.372.54 1748
Method of Investigation of the Four-Branch Reactive Ladder-Filter Section—J. Bimont. [*Câbles & Trans.* (Paris), vol. 14, pp. 175–179; July, 1960.] An extension of a graphical method described earlier (3738 of 1960) is given.

621.372.54 1749
Antimetric Ladder Filters—J. E. Colin. [*Câbles & Trans.* (Paris), vol. 14, pp. 200–219; July, 1960.] All parameters of a quadripole antimetric ladder filter are shown to depend on four polynomial functions of p^2 (p being the complex angular frequency) between which a relation exists. The theory is applied to antimetric band rejection filters and to high- and low-pass filters, and tables are given facilitating calculations.

621.372.54 1750
Extension of the Possibilities of Filter Circuit Construction by means of Regions of Imaginary Characteristic Impedance in the Pass Band and Regions of Real Characteristic Impedance in the Stop Band—W. Herzog. (*Nachrtech. Z.*, vol. 13, pp. 291–295; June, 1960.) See also 1434 of May.

621.372.54:621.374 1751
The Choice of Filters with Favourable Transient Characteristics—O. Herrmann and W. Schüssler. (*Arch. elekt. Übertragung*, vol. 14, pp. 183–189; April, 1960.) The design of networks with the desired characteristics for pulse-shaping circuits is based on an analog-computer method [3737 of 1960 (Schüssler)]. Examples are given of filters with idealized response or with transfer function approximated by polynomials.

621.372.54:621.375.13.029.4 1752
Audio-Frequency Comb-Filter—L. H. Bedford. (*Electronic Tech.*, vol. 38, pp. 138–140; April, 1961.) Details are given of the design of a mechanical system consisting of a stretched metallic string for supressing 50-cps hum and associated harmonics in the output of an AF amplifier. Experimental results are noted.

621.372.6 1753
The Scattering Matrix of Generally Interconnected Multipoles—T. A. Abele. (*Arch. elekt. Übertragung*, vol. 14, pp. 262–268; June, 1960.) The scattering matrix of the network is formed by the simple manipulation of matrices based on the scattering matrix of the individual multipoles. See also 3399 of 1960 (Schuon and Wolf).

621.373.029.66 1754
Research on Submillimetre Wave Generation and Techniques—G. E. Weibel. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1015–1020; October 8, 1960. In English.) Experiments and experimental equipment are described for investigations on sub-mm-wave generation, including a "tornadotron" in which EM radiation is produced by the action of pulsed magnetic fields, of the order of 100 kg, on a trapped electron cloud. Aspects of instrumentation suitable for these frequencies are briefly discussed.

621.373.4:621.376.32 1755
Frequency Modulation of a Pound Stabilized Oscillator—K. Leibrecht. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3302–3304; May 16, 1960.) A method is outlined for applying frequency modulation to an improved pound stabilized oscillator [355 of 1956 (Hervé)]. The frequency deviation is limited to about 1 Mc.

621.373.4.072.9 1756
Impulse-Governed Oscillator-Techniques: Part 2—C. J. de Lussanet de la Sablonière. (*Philips Telecommun. Rev.*, vol. 22, pp. 32–46 and 94–101; September, 1960, and January, 1961.) Theoretical aspects of IGO techniques are given. Part 1: 3754 of 1960.

621.373.42.029.6:621.018.41(083.74) 1757
Microwave Generators for the I.E.N. Caesium Standard—G. Zito. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1075–1079; October 8, 1960. In English.) Two microwave generators are described which are used in the atomic frequency standard of the Istituto Elettrotec-

nico Nazionale in Turin for Cs resonance excitation by molecular-beam technique. Measurements of phase drift and frequency stability are also considered.

621.373.422 1758
Plate Voltage Control of Phantastron Frequency—W. C. Whitworth. (*Electronics*, vol. 34, pp. 73–74; February 10, 1961.) "Two pentodes, each forming a phantastron circuit, are interconnected so that both mark and space of their combined output waveforms are controlled by linear rather than exponential sweeps. Circuit jitter is less than 0.003% at 5 pulses/sec repetition rate."

621.373.422:621.382.333 1759
Phantastron Circuits using Transistors—N. C. Hekimian. (*Electronics*, vol. 34, pp. 46–47; February 24, 1961.) Arrangements of three transistors to simulate the screen/anode current partition of a pentode enable transitron-type circuits to be designed are given.

621.373.43:621.374.32 1760
The Eccles-Jordan Circuit with Transistors for High-Speed Counters—W. Hilberg. (*Telefunken Ztg.*, vol. 33, pp. 98–108; June, 1960. English summary, p. 156.) A static analysis of a transistor flip-flop circuit is given, and the counting frequency limits for high-speed counters consisting of balanced flip-flop elements are discussed. Circuits operating at frequencies in excess of 20 Mc are described.

621.373.43:621.382.23 1761
One-Tunnel-Diode Flip-Flop—R. A. Kaenel. (PROC. IRE, vol. 49, p. 622; March, 1961.) A note on the operation of a simple bistable device is given.

621.373.43:621.382.23 1762
Designing Tunnel-Diode Oscillators—W. H. Ko. (*Electronics*, vol. 34, pp. 68–72; February 10, 1961.) An analysis of relaxation oscillators and associated circuits for sine-wave and square-wave generation is given.

621.374.3 1763
Mathematical Analysis of Pulse Networks—R. Hofmann. (*Arch. elekt. Übertragung*, vol. 14, pp. 255–261; June, 1960.) Linear systems are analyzed which comprise an element capable of converting a continuous input function into pulses of any desired shape. A pulse-network equation is derived which is applicable to closed-loop control systems.

621.374.3 1764
The Generation of Very Short Needle-Shaped Pulses—H. P. Louis. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1067–1072; October 8, 1960.) The design of pulse generators and pulse-shaping networks is discussed. Details are given of a double-differentiating network for the generation of 0.35-nsec pulses of 400-mv amplitude; further improvements by means of tunnel diodes appear possible.

621.374.33:621.387.4 1765
Low-Level Linear Microsecond Gate—P. R. Chagnon. (*Rev. Sci. Instr.*, vol. 32, pp. 68–70; January, 1961.) A six-diode gate, linear over the range 0.01–5 v is described.

621.374.5 1766
A Solenoid Delay Line with Constant Delay—A. J. Giger. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 960–962; October 8, 1960.) A description is given of a compact delay line which consists of a solenoid wound on a ceramic tube of high dielectric constant with a metal core. Delay can be made independent of frequency with an appropriate tube/core diameter ratio.

621.374.5:534.2–8 1767
The Effect of an Intermediate Layer on the Frequency Characteristics of Ultrasonic Delay Lines—K. S. Aleksandrov, L. S. Gurovits, and E. I. Kamenskiĭ. (*Akust. Zh.*, vol. 6, no. 2, pp. 171–179; 1960.) General expressions are derived for the line conversion factor taking account of an intermediate layer between the transducer and the line. The effect of this layer on the frequency characteristics and transmission band is considered and the relevant characteristics of different transducer and layer materials are tabulated.

621.375.029.6:[621.385.6+621.382.23 1768
Amplification—Modern Trends, Techniques and Problems—Nergaard. (See 2044.)

621.375.432 1769
The Behaviour of a Nonlinear Transistor Amplifier in the Region of its Stability Limit—I. Gumowski. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3142–3144; May 9, 1960.) An extension of earler work (4150 of 1960 and 801 of March) is discussed. The limit of stability of the amplifier is established from the form of the solution of a first-order differential equation describing the amplifier is given.

621.375.432 1770
Transistor Amplifiers with Feedback—E. R. Hauri. (*Tech. Mitt. PTT*, vol. 38, pp. 185–200 and 228–236; June 1, and July 1, 1960.) An analysis of the properties of transistor amplifiers using the h parameters is given. Feedback circuits with special characteristics are reviewed. Over 40 references.

621.375.9:537.311.33 1771
Semiconductor Amplifiers and Generators with Carriers having Negative Effective Mass—N. G. Basov, O. N. Krokhin, and Yu. M. Popov. (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 1001–1002; March, 1960.) It is not possible to produce, in a semiconductor, states with negative losses by means of a constant electric field; it is necessary to have a state with negative temperature as achieved in molecular generators or using pulsed excitation by an electric field.

621.375.9:538.569.4 1772
Cross-Relaxation Masers—G. S. Bogle. (PROC. IRE, vol. 49, pp. 573–590; March, 1961.) The ways in which ruby, spinel, rutile and emerald can amplify at frequencies small compared with their zero-field splitting frequencies are surveyed. Cross-relaxation is shown to give a two-fold improvement in maser performance. Analytic expressions for the energies are given.

621.375.9:538.569.4 1773
Seesaw Maser Operation—P. A. Forrester and W. B. Mims. (*J. Appl. Phys.*, vol. 32, pp. 317–320; February, 1961.) "Cross relaxation between adjacent intervals may be used to secure an advantage in maser operation comparable to that obtained by 'push-pull' pumping. Equations for the rate of change of populations in a scheme of four levels (A, B, C, D) when AC is pumped and cross relaxation takes place between BC, CD have been formulated, and the steady-state condition corresponding to various assumptions regarding lattice relaxation times is discussed. In an experimental investigat on of maser operation based on this scheme and using ruby as the active material, an inversion of 0.9:1 was obtained at a signal frequency of 14.5 Gc/s when pumping at 24.5 Gc/s."

621.375.9:621.372.44 1774
Travelling-Wave Parametric-Amplifier Analysis using Difference Equations—H. Zucker. (PROC. IRE, vol. 49, pp. 591–598; March, 1961.) A second-order difference equation is derived for both periodically and uniformly distributed parametric amplifiers. Gain and voltage output are calculated. The results are specifically applied to an LC-distributed parametric amplifier.

621.375.9:621.372.44 1775
Effect of Upper Sidebands in Travelling-Wave Parametric Amplifiers—A. Dayem. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1054–1061; October 8, 1960. In English.) The effect of higher sidebands on paramagnetic amplification is investigated for circuits of limited bandwidth and infinite bandwidth [see *e.g.*, 3240 of 1959 (Roe and Boyd)].

621.375.9:621.372.44:523.164 1776
Theoretical Considerations regarding the Application of Parametric Amplifiers to Radio Telescopes—W. Druey and H. Rickenbach. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1061–1067; October 8, 1960.) The improvement of resolving power obtained by using one parametric amplifier immediately preceding the antenna and another as the preamplifier stage of the receiver is discussed.

621.375.9:621.372.44:523.164 1777
Parametric Amplifier for Space Probe Tracking—C. F. Brett. (*Electronics*, vol. 34, pp. 41–45; January 27, 1961.) A description of the parametric amplifier used with the Jodrell Bank Radio telescope for reception of the Pioneer V space probe signals from distances of over 22×10^6 miles is given. A description of a parametric-amplifier tester using transistors is included.

621.375.9:621.372.44:538.221 1778
Parametric Circuits at Low Frequencies using Ferrites and Thin Magnetic Films—A. Brändli. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1046–1053; October 8, 1960. In English.) The design of parametric circuits incorporating ferrite cores and films with nonlinear B/H characteristics is discussed. Films appear to be more suitable for operation at higher frequencies. An advantage of the use of ferrite and magnetic-film devices is their resistance to nuclear radiation.

621.375.9:621.372.44:621.385.3 1779
The Reactance Tube as a Parametric Frequency Divider and Amplifier—R. A. Elco and J. Nee. (PROC. IRE, vol. 49, pp. 624–625; March, 1961.) A derivation of the equivalent circuit of a parametric amplifier in which a reactance tube functions as a time-varying inductance is given. If the signal source is removed, the circuit will operate as a frequency divider, where the output is a subharmonic of the pump frequency.

621.375.9:621.372.44:621.385.63 1780
Energy Balance in a Parametric Electron-Beam Amplifier—Grau. (See 2046.)

621.375.9:621.372.44:621.385.63 1781
Coupled-Mode Theory of Electron-Beam Parametric Amplification—Gould and Johnson. (See 2047.)

621.375.9:621.372.44:621.385.63 1782
A Cyclotron Wave Amplifier with Magnetic Pumping—Robson. (See 2048.)

621.375.9.049.75:621.382.23 1783
Designing Tunnel-Diode R.F. Amplifiers—E. D. Long and C. P. Womack. (*Electronics*, vol. 34, pp. 120–123; February 17, 1961.) A strip-line filter and tunnel diode are combined to give low-noise amplification at UHF in a small module.

GENERAL PHYSICS

537.291 1784
Time-Averaged Effects on Charged Particles in A.C. Fields—T. W. Johnston. (*RCA*

Rev., vol. 21, pp. 570–610; December, 1960.) The basic theory is developed and applied to plasmas, including some cases with a dc magnetic field. A bibliography and a critique of theory and experiments are included.

537.32 1785
Transient Response of a Thermocouple Circuit under Steady Currents—A. D. Reich and J. R. Madigan. (*J. Appl. Phys.*, vol. 32, pp. 294–301; February, 1961.)

537.533 1786
Experimental Study of Anomalous Electron Stream Behavior—M. H. Miller and W. G. Dow. (*J. Appl. Phys.*, vol. 32, pp. 274–281; February, 1961.) Experimental measurements on the characteristics of the sole current in a rectilinear crossed-field beam are reported. The sole current may be assigned a kinetic temperature of the order of 10 v corresponding to energy in excess of that corresponding to motion in static fields. The energy exchange leading to this excess energy is believed to be associated with multiple-loop trajectories in the low-potential region near the cathode.

537.54:621.391.822 1787
Noise Generated in the Ion Sheath of a Probe—K. Shimada. (PROC. IRE, vol. 49, pp. 632–633; March, 1961.) The frequency-dependence of I_{eq}, the saturated diode current, is examined theoretically and results obtained are compared with measured values.

537.56 1788
The General Theory of the Motions of Ions and Electrons in Gases—L. G. H. Huxley. (*Aust. J. Phys.*, vol. 13, pp. 718–737; December, 1960.) The chief formulas for the drift velocities and diffusion coefficients of ions and electrons in gases are derived in general form by the application of dynamical principles.

537.56 1789
An Error in the Thermal Conductivity for a Fully Ionized Gas—R. W. Vaughan-Williams and F. A. Haas. (*Phys. Rev. Lett.*, vol. 6, pp. 165–166; February 15, 1961.) A discrepancy between formulas of Marshall and of Rosenbluth and Kaufmann (1703 of 1958) is due to an error in the last collision integral of Marshall.

537.56 1790
The Investigation of High-Frequency Plasmas by means of a D.C. Probe—H. Fetz and H. Oechsner. (*Z. angew. Phys.*, vol. 12, pp. 250–253; June, 1960.)

537.56 1791
Instability of Longitudinal Oscillations of an Electron-Ion Plasma—L. M. Kovrizhnykh and A. A. Rukhadze. (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 850–853; March, 1960.) In an isotropic plasma the oscillations are always damped; in an anisotropic medium ion motion may lead to instability.

537.56:537.533 1792
Interaction of an Electron Beam with Plasma—I. F. Kharchenko, Ya. B. Faĭnberg, R. M. Nikolaev, E. A. Kornilov, E. A. Lutsenko, and N. S. Pedenko. (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 685–692; March, 1960.) An experimental investigation of modulated and unmodulated beams of high-energy electrons with a high-frequency discharge plasma is reported. When an unmodulated beam moves through the plasma, oscillations are produced in the beam at frequencies close to the plasma frequency.

537.56:537.533 1793
Interaction of an Electron Beam with a Fully Ionized Plasma—M. A. Allen and G. S. Kino. (*Phys. Rev. Lett.*, vol. 6, pp. 163–165; February 15, 1961.) An electron beam, modulated at microwave frequency ω, passes through a thermal Cs plasma (critical frequency ω_p, cyclotron frequency ω_c). Gain in beam modulation amplitude is measured. Theory is outlined which predicts gain for $\omega_c^2<\omega^2<\omega_c^2+\omega_p^2$ with a maximum at $\omega=\omega_p$. Preliminary experiments agree with theoretical predictions. A measured gain>20 db at 3 Gc is reported.

538.24 1794
Magnetic Polarizability of a Short Right Circular Conducting Cylinder—T. T. Taylor. (*J. Res. NBS*, vol. 64B, pp. 199–210; October–December, 1960.) A comprehensive mathematical analysis using a method given earlier (488 of February) is described.

538.311:537.312.62 1795
Production of Magnetic Fields exceeding 15 Kilogauss by a Superconducting Solenoid—J. E. Kunzler, E. Buehler, F. S. L. Hsu, B. T. Matthias, and C. Wahl. (*J. Appl. Phys.*, vol. 32, pp. 325–326; February, 1961.) Experiments with Mo_3Re in wire form are described. Critical-field data are given.

538.561:539.124 1796
Cherenkov Radiation of a Particle Possessing a Charge and an Intrinsic Magnetic Moment—Li Men Kha (Li Meng-Ha). (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 934–936; March, 1960.) An analysis, by quantum electrodynamic methods, of the effect of the spin on the intensity and polarization of the radiation produced in a ferrite by a charged particle with an intrinsic magnetic moment is given.

538.566+534.2 1797
Energy-Momentum Tensor for Plane Waves—P. A. Sturrock. (*Phys. Rev.*, vol. 121, pp. 18–19; January 1, 1961.) A general form is established for the energy momentum tensor for plane waves propagating in a homogeneous medium, the field equations of which are derivable from a quadratic Lagrangian function.

538.566+534.2 1798
Limit of Applicability of the Method of "Smooth" Perturbations in the Problem of Wave Propagation through a Medium with Inhomogeneities—V. V. Pisareva. (*Akust. Zh.*, vol. 6, no. 1, pp. 87–91; 1960.) Mean square values of the phase and amplitude fluctuations and of the amplitude correlation function are discussed. Conditions are determined under which the effect of the layer with inhomogeneities on the traversing radiation can be replaced by the perturbation action of an equivalent phase screen.

538.566:535.42]+534.26 1799
Diffraction of a Scalar Wave by a Slit and by a Circular Aperture in a Screen of Arbitrary Thickness—M. V. Butrov. (*Akust. Zh.*, vol. 6, no. 1, pp. 16–22; 1960.) An expression is derived for the transmission coefficient, and its variation as a function of screen thickness and aperture size is plotted.

538.566:535.42 1800
An Electromagnetic Diffraction Problem involving Unidirectionally Conducting Surfaces—R. A. Hurd. (*Canad. J. Phys.*, vol. 38, pp. 1229–1244; October, 1960.) The exact value of the EM field scattered by a unidirectionally conducting surface under plane wave excitation is obtained. The surface, which is an entire plane, is the junction of two unidirectionally conducting half-planes whose conductivity directions are inclined at an arbitrary angle to each other and to the boundary line.

538.566:535.42 1801
On the Theory of Diffraction by a Composite Cylinder—R. D. Kodis. (*J. Res. NBS*, vol. 65D, pp. 19–33; January/February, 1961.) General formulas are developed for the diffraction field around a perfectly conducting cylinder with a dielectric sleeve. These formulas represent the field due to a unit electric line source parallel to the cylinder. Limiting cases are examined.

538.566:537.56 1802
Gyro-resonance Absorption of Electromagnetic Waves in a Plasma—B. N. Gershman. (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 912–924; March, 1960.) An earlier analysis (1476 of May) is extended to frequencies near the gyrofrequency and multiples of this, taking account of the thermal motion of electrons.

538.566.029.64:530.17:535.43 1803
Microwave Analogue to the Scattering of Light by Nonspherical Particles—J. M. Greenberg, N. E. Pedersen, and J. C. Pedersen. (*J. Appl. Phys.*, vol. 32, pp. 233–242; February, 1961.) Total scattering cross sections and angular distributions have been measured; some approximate theoretical methods appear to be useful. The results are referred to the effects of interstellar matter on starlight.

538.569.4:535.853 1804
Paramagnetic Resonance Spectroscopy at Zero Magnetic Field—G. S. Bogle, H. F. Symmons, V. R. Burgess, and J. V. Sierins. [*Proc. Phys. Soc.* (London), vol. 77, pp. 561–566; March 1, 1961.] Two spectrometers covering the range 8–18 Gc are described.

538.569.4:535.853:621.316.726 1805
Frequency Stabilization Scheme for the Pound-Watkins R.F. Spectrometer—J. Jeener. (*Rev. Sci. Instr.*, vol. 32, pp. 27–28; January, 1961.) "A scheme is described for locking the frequency of a marginal-oscillator r.f. spectrometer to that of an external standard. This makes it convenient to use such a spectrometer for high-resolution NMR work."

538.569.4:535.853:621.375.9 1806
Comparison of the Sensitivities of the Beam Maser and Cavity Absorption Spectrometers—Y. Beers. (*Rev. Sci. Instr.*, vol. 32, pp. 23–27; Januray, 1961.) A formula is derived for the SNR of the beam maser considering it as a special case of cavity spectrometer. The sensitivity of the maser relative to the spectrometer varies inversely with the frequency.

538.569.4:538.221 1807
Restoration of Stability in Ferromagnetic Resonance—H. Suhl. (*Phys. Rev. Lett.*, vol. 6, pp. 174–176; February 15, 1961.) The threshold RF power for subsidiary absorption can be increased by a small ac modulation of the dc magnetic field.

538.569.4:621.373.421.1 1808
High Level Oscillator for Nuclear Resonance—W. D. Knight. (*Rev. Sci. Instr.*, vol. 32, p. 95; January, 1961.) A modification of the cathode-coupled circuit [see *e.g.*, 1972 of 1960 (Robinson)] which functions at RF levels in the range 1–10 v rms is given.

538.569.4:621.375.9:535.61–1/2 1809
Theory of LASER Oscillation in Fabry-Perot Resonators—J. Kotik and M. C. Newstein. (*J. Appl. Phys.*, vol. 32, pp. 178–186; February, 1961.) An approximate condition for oscillation is derived.

538.569.4:621.375.9:535.61-2 1810
Stimulated Optical Emission from Exchange-Coupled Ions of Cr^{+++} in Al_2O_3—I. Wieder and L. R. Sarles. (*Phys. Rev. Lett.*, vol. 6, pp. 95–96; February 1, 1961.)

538.569.4:621.375.9:535.61-2 1811
Simultaneous Optical Maser Action in Two Ruby Satellite Lines—A. L. Schawlow and G. E. Devlin. (*Phys. Rev. Lett.*, vol. 6, pp. 96–

98; February 1, 1961.) Maser oscillations have been obtained simultaneously at wavelengths of 7,009 Å and 7,041 Å in concentrated ruby.

538.569.4:621.375.9:535.61-2 1812
Population Inversion and Continuous Optical Maser Oscillation in a Gas Discharge containing a He-Ne Mixture—A. Javan, W. R. Bennett, Jr., and D. R. Herriott. (*Phys. Rev. Lett.*, vol. 6, pp. 106–110; February 1, 1961.) Experimental data on the physical properties of the system are discussed.

538.569.4.029.64/.65:546.217 1813
Radio Wave Absorption of Several Gases is the 100 to 117 kMc/s Frequency Range— C. O. Britt, C. W. Tolbert, and A. W. Straiton. (*J. Res. NBS*, vol. 65D, pp. 15–18; January/February, 1961.) An extension of earlier work [2699 of 1960 (Straiton and Tolbert)] to the gases CO, N_2O, SO_2 and NO_2 is given. The gases were contained within a $6\frac{1}{8}$-inch-diameter tube up to 500 feet long, and a wide pressure range was used.

538.569.4.029.65:535.223 1814
Precise Measurement of the Microwave Absorption Frequencies of the Oxygen Molecule and the Velocity of Light—R. W. Zimmerer and M. Mizushima. (*Phys. Rev.*, vol. 121, pp. 152–155; January 1, 1961.) "Ten microwave absorption frequencies of the oxygen molecule in the 60-Gc/s region have been measured with an accuracy of about 10 kc/s. The result is interpreted by successfully refining the existing theory. Comparing the resultant value of the rotational constant B_0 with the value obtained in ultraviolet spectra, the velocity of light is calculated to be 299,773 ±12 km/s."

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.164 1815
A Catalogue of Radio Sources between Declinations −20° and −50°—B. Y. Mills, O. B. Slee, and E. R. Hill. (*Aust. J. Phys.*, vol. 13, pp. 676–699; December, 1960.) This list of 892 sources supplements a previous catalogue for declinations between +10° and −20° (423 of 1959). Angular sizes of 50 of the strongest sources are given, several of these being less than 15-seconds arc in size.

523.164:621.396.62 1816
A 75-cm Receiver for Radio Astronomy and some Observational Results—C. L. Seeger, F. L. H. M. Stumpers, and N. van Hurck. (*Philips Tech. Rev.*, vol. 21, pp. 317–333; September 27, 1960.) A description is given of a superheterodyne receiver in which the HF amplifier contains two disk-seal triode tubes in cascode, the effective cathode resistance of the second tube being made very high by a simple neutralization circuit. A noise factor of 2.5 has been obtained at 400 Mc. Radio-astronomy observations are described which have been made with this receiver and the 25-m parabolic reflector at Dwingeloo. An isophot chart of the sky drawn from these observations is reproduced.

523.164:621.396.677 1817
An Interferometer for the Measurement of Radio-Source Sizes—B. R. Goddard, A. Watkinson, and B. Y. Mills. (*Aust. J. Phys.*, vol. 13, pp. 665–675; December, 1960.) The 85.5-Mc cross-type radio telescope at Sydney [1126g of 1958 (Mills, *et al.*)] has been modified to study sources in the range 100 seconds–1 minute arc. The instrument and its operation are described.

523.164:621.396.677.5/.6 1818
Direction-Finding on Diffuse Sources of Electromagnetic Radiation—D. G. Cartwright. (*Aust. J. Phys.*, vol. 13, pp. 712–717; December, 1960.) By combining the characteristics of an Adcock type and rotating-loop type of direction-finder the position and size of an extended source can be determined.

523.164.3 1819
An Attempt to Detect Linear Polarization in the Galactic Background Radiation at 215 Mc/s—J. L. Pawsey and E. Harting. (*Aust. J. Phys.*, vol. 13, pp. 740–742; December, 1960.) Observations of a strip of sky about declination 34°S set an upper limit of 1 per cent to the degree of linear polarization for bandwidths of 1 Mc, 700 and 300 kc.

523.164.32 1820
Recent Developments in Solar Radio Astronomy—A. Maxwell. (*Proc. Natl. Acad. Sciences*, vol. 46, pp. 1260–1269; September, 1960.) A review with 24 references is given.

523.164.32 1821
The Radio Brightness of the Quiet Sun at 21 cm Wavelength near Sunspot Maximum—N. R. Labrum. (*Aust. J. Phys.*, vol. 13, pp. 700–711; December, 1960.) The quiet-sun temperature, measured using pencil-beam and fan-beam techniques, is approximately 140,000°K. This value is twice that for the same wavelength at sunspot minimum.

523.164.32:523.75 1822
Investigation of the Relative Positions of Solar Radio Storm Sources and of Associated Optical Centres of Activity—É. J. Blum and A. M. Malinge. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3119–3121; May 9, 1960.) A comparison has been made between the mean positions of radio storm centers observed on 169 Mc and optically observed sunspots. Results show a systematic difference between the apparent and true positions of the former and, for more intense storm centers, a directivity effect with latitude.

523.164.32:550.385.4 1823
Solar Radio Em ssions and Geophysical Disturbances during July 1959—M. P. Hughes. (*J. Geophys. Res.*, vol. 66, pp. 651–653; February, 1961.)

523.164.4 1824
Cosmological Significance of Angular Measurements of Distant Radio Sources—W. Davidson. (*Nature*, vol. 189, pp. 991–992; March 25, 1961.)

523.165 1825
Solar-Produced Cosmic Rays near the North and South Poles—M. A. Pomerantz, S. P. Duggal, and K. Nagashima. (*Phys. Rev. Lett.*, vol. 6, pp. 123–125; February 1, 1961.) Results of ground observations during the storms of November 12th and 15th, 1960, are presented.

523.165 1826
X Rays from Van Allen Belt Electrons—J. B. Cladis and A. J. Dessler. (*J. Geophys. Res.*, vol. 66, pp. 343–350; February, 1961.) It ought to be possible to detect the X-ray flux, at peak intensity, above the cosmic radiation background at balloon altitudes.

523.165 1827
Electrons in the Primary Cosmic Radiation—P. Meyer and R. Vogt. (*Phys. Rev. Lett.*, vol. 6, pp. 193–196; February 15, 1961.) Extraterrestrial electrons with energies in the range 25–1300 Mev and greater have been observed on three balloon flights.

523.165 1828
Charged Particles in the Inner Van Allen Radiation Belt—A. H. Armstrong, F. B. Harrison, H. H. Heckman and L. Rosen. (*J. Geophys. Res.*, vol. 66, pp. 351–357; February, 1961.) Results are given for the flight through the inner Van Allen belt of emulsion stacks carried in an Atlas rocket. The measured proton energy spectrum was in accord with a cosmic ray albedo source down to 100 Mev. However, below 100 Mev the spectrum exhibits structure with a maximum at 80 Mev and a minimum at 60 Mev. Penetration of solar protons into the belt over a period of days can explain the effect.

523.165:539.16 1829
Hydromagnetic Waves and the Trapped Radiation: Parts 1 & 2—D. G. Wentzel. (*J. Geophys. Res.*, vol. 66, pp. 359–369; February, 1961.) A theoretical discussion and comments on the results of the Argus experiment are given.

523.746.5 1830
An Estimate of the Peak Sunspot Number in 1968—C. M. Minnis. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 94 99; March, 1961.) A detailed analysis was made of the statistical properties of the twenty peaks in the sunspot cycle since 1761, the results of which were given earlier (2341 of 1960).

523.75:523.164.32 1831
Unusual Solar Disturbance—(*Tech. News Bull. NBS*, vol. 44, pp. 138–139; August, 1960.) No solar flare could be observed at the time of a radio disturbance of importance 3+ at 1638 U.T. on June 9, 1959. The flare became observable after a delay of $1\frac{1}{2}$ hours. This and other anomalies are discussed in relation to two assumptions concerning the flare: a) that it occurred on the far side of the sun, b) that it originated at a lower level in the sun's atmosphere than the source of RF emissions.

550.385.37 1832
Geomagnetic Micropulsations—G. R. A. Ellis. (*Aust. J. Phys.*, vol. 13, pp. 625–632; December, 1960.) Simultaneous observations of geomagnetic pulsations at geomagnetic latitudes 28°S, 42°S and 51°S showed no change in period with latitude, but a monotonic increase in amplitude with latitude for periods between 10 and 100 sec. The interpretation of these results is discussed.

550.385.4 1833
The Simultaneity of Geomagnetic Sudden Impulses—M. Yamamoto and H. Maeda. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 212–215; March, 1961.) An analysis of several events during the I.G.Y. shows that sudden impulses are propagated from high latitudes to low latitudes in times of about 1 minute.

551.507.362.2 1834
The Theory of Artificial Satellites in Terms of the Orbital True Longitude—P. Musen. (*J. Geophys. Res.*, vol. 66, pp. 403–409; February, 1961.) Previous theory (1589 of 1960) has been developed in terms of orbital true longitude and leads to faster convergence for large eccentricities and to a smaller number of terms in the series representing the perturbations.

551.507.362.2:621.391.812.3 1835
On the Large-Scale Regions of Irregularities Producing Scintillation of Signals Transmitted from Earth Satellites—J. Frihagen and J. Tröim. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 215–216; March, 1961.) Evidence is presented which indicates that absence of scintillation is not due primarily to high aspect sensitivity scattering from field-aligned irregularities.

551.507.362.2:621.391.812.3 1836
Ionospheric Scattering of Satellite Transmissions—J. Maudsley and I. R. Richards. (*Nature*, vol. 189, pp. 906–907; March 18, 1961.) Reports of observations of nighttime scintillations of satellite transmissions are briefly analyzed in relation to the position of the observing station and the direction of pas-

sage of the satellite. Results demonstrate the ability of field-aligned irregularities to scatter m-λ radio waves in a manner highly sensitive to aspect. See also 1160 of April (Bain).

551.507.362.2:621.391.812.34 1837
Observed Field Strength in the Neighbourhood of the Skip Distance—K. C. Yeh and G. W. Swenson, Jr. (*J. Geophys. Res.*, vol. 66, pp. 654–656; February, 1961.) Examples of ray focusing due to the satellite 1958 δ_2 crossing the skip-distance boundary are given. The skip distance agrees well with values derived from ionograms.

551.510.535 1838
Ion-Neutral Reactions—M. Hertzberg. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 177–182; March, 1961.) A list is given of reactions which may control the chemical composition of positive ions in the ionosphere. Under certain assumptions about reaction rate coefficients, nitrogen is substantially dissociated in the F region, contrary to the theoretical conclusions of other investigators.

551.510.535 1839
A Preliminary Model for the Variations of Upper Air Densities—H. K. Paetzold. (*Nature*, vol. 190, pp. 35–36; April 1, 1961.) A model is proposed covering variations of density with a period greater than one day.

551.510.535 1840
The Highest Parts of the Ionosphere—J. A. Ratcliffe. (*Quart. J. R. Met. Soc.*, vol. 85, pp. 321–331; October, 1959.) The text is given of the Symons Memorial Lecture, 1959, reviewing current theories concerning the formation and structure of the ionosphere above 150 km.

551.510.535 1841
Incoherent Scattering by Free Electrons as a Technique for Studying the Ionosphere and Exosphere: some Observations and Theoretical Considerations—K. L. Bowles. (*J. Res. NBS*, vol. 65D, pp. 1–14; January/February, 1961.) Observations confirm the existence of the incoherent scatter at predicted levels but indicate less Doppler broadening than expected, for which an explanation is offered.

551.510.535 1842
A Possibility for Determining the Existence of a Permanent Form of Magnetic Field-Aligned Ionization Irregularities—R. L. Leadabrand. (PROC. IRE, vol. 49, pp. 639–640; March, 1961.) Incoherent scatter from a direction perpendicular to the earth's magnetic field is discussed.

551.510.535 1843
Internal Atmospheric Gravity Waves at Ionospheric Heights—C. O. Hines. (*Canad. J. Phys.*, vol. 38, pp. 1441–1481; November, 1960.) Irregularities and irregular motions observed in the upper atmosphere are interpreted in terms of a spectrum of waves propagated upwards and modified to produce different dominant modes at different heights.

551.510.535 1844
Vertical Characteristics of Travelling Ionospheric Disturbances—L. H. Heisler. (*Aust. J. Phys.*, vol. 13, pp. 655–664; December, 1960.) A comparison between the occurrence of disturbances on fixed-frequency records and $N(h)$ profiles for the same period reveals that a) there appears to be an upper-limiting height for the occurrence of disturbances on fixed frequency, and b) the direction of travel of disturbances is related to season only and seems unrelated to height in the ionosphere.

551.510.535 1845
The Analysis of Night-Time $h'(f)$ Records—J. Titheridge. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 209–212; March, 1961.) A correction of electron density profiles for errors due to underlying ionization, by the use of the extraordinary ray, is given.

551.510.535 1846
Theoretical World Curves of Maximum F_2 Ionization: Part 2—J. E. C. Gliddon and P. C. Kendall. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 183–188; March, 1961.) A time-dependent solution of the continuity equation, including vertical diffusion of ionization, is used to obtain a theoretical variation of maximum F_2-layer electron density with latitude and local time. Some similarity to experimental data is found, but the equatorial "trough" does not occur in the theoretical solution. See also 2738 of 1960.

551.510.535 1847
On the Influence of Horizontal Motion of the Neutral Air on the Diffusion Equation of the F Region—J. P. Dougherty. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 167–176; March, 1961.) The equations of motion of a plasma in applied fields are discussed with reference to the F region. The plasma sets the neutral air into motion horizontally within about $\frac{1}{2}$ h, but is not free to move vertically. The consequences of this result, on a worldwide scale, are discussed.

551.510.535:550.385.36 1848
Movements of the F Layer of the Ionosphere during Geomagnetic Bay Disturbances—H. Kohl. (*Arch. elekt. Übertragung*, vol. 14, pp. 169–176; April, 1960.) The vertical movement of the F layer during and after geomagnetic disturbances is evaluated from ionospheric soundings made at Lindau, Germany. The movement is treated theoretically on the basis of the plasma theory developed by Lucas and Schlüter (2085 of 1954), and to account for the rise of the layer use is made of Martyn's theory allowing for the influence of the neutral gas. By comparing calculated and measured data, estimates of conductivity and neutral-gas density in the ionosphere can be made.

551.510.535:550.385.4 1849
The Occurrence of the Spread F and the Geomagnetic Field—T. Shimazaki. (*J. Radio Res. Labs., Japan*, vol. 7, pp. 437–450; September, 1960.) Spread-F is more probable in days after a sudden commencement at high latitudes, and less probable at low altitudes, especially at the equinoctial seasons. There is a strong correlation between the magnitude of the geomagnetic field and the occurrence of spread-F at low latitudes; a turbulence mechanism is suggested to explain this.

551.510.535:551.507.362.1 1850
Measurement of Positive-Ion Density in the Ionosphere by Sounding Rocket—T. Ichimiya, K. Takayama, T. Dote, Y. Aono, K. Hirao, S. Miyazaki, T. Sugiyama, and T. Muraoka. (*Nature*, vol. 190, pp. 156–158; April, 1961.) Preliminary results are given of measurements made over the Akita Rocket Range, Japan, in September, 1960. Two rockets were launched, one during the daytime and one at night, each equipped with a spherical Langmuir probe. Ascent and descent records for each flight show close agreement and the values of electron density scaled from $h'(f)$ records agree fairly well with those obtained from rocket measurements.

551.510.535:621.3.087.4 1851
Vertical Incident Doppler Ionogram—T. Ogawa, S. Ando, and A. Yoshida. (PROC. IRE, vol. 49, p. 643; March, 1961.) An improved apparatus has been constructed for the measurement of Doppler shifts produced by vertical movements of the ionosphere.

551.510.535:621.3.087.4 1852
Contribution to an Investigation of Ionospheric Absorption on a Fixed Frequency—G. Pillet. (*Ann. Télécommun.*, vol. 15, pp. 157–184 and 198–219; July/August and September/October, 1960.) A thesis, concerning theoretical and experimental aspects of ionospheric absorption measurements by vertical-incidence sounding is given. Measurements made on a frequency of 3.4 Mc during the period September, 1955–March, 1958, are analyzed. 74 references.

551.510.535:621.391.812.63 1853
Determination of the Ionospheric Absorption from Recordings of Field Strength and Cosmic Noise—H. Schwentek. (*Arch. tech. Messen*, no. 296, pp. 177–180; September, 1960.) Brief descriptions are given of a method of determining the ionospheric absorption index from oblique incidence recordings (see also 2732 of 1959), and of the riometer method using extraterrestrial noise sources [1566 of 1959 (Little and Leinbach)].

551.510.535(98):621.391.812.631 1854
Statistical Study on the Occurrence of Polar Blackouts—I. Kasuya. (*J. Radio Res. Labs., Japan*, vol. 7, pp. 451–465; September, 1960.) The distributions of radio blackouts in both hemispheres are examined using $f_{\min}$ data at 31 stations in the north and 12 stations in the south. The changes of blackout occurrence and times of maximum occurrence frequency with position are studied.

551.510.536 1855
A Theoretical Model of Electron Density Distribution along a Geomagnetic Line of Force in the Exosphere—R. L. Dowden. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 122–130; March, 1961.) A model of electron density in the exosphere is set up by supposing electrons to diffuse along tubes of force. Electron densities in ionosphere and exosphere are related by steady-state solutions. The particle source is in the ionosphere under normal conditions, but during the magnetic storm particles are injected into a tube of force at its furthest point from earth. The role of collisions is discussed.

551.594.5:621.396.96 1856
A Note on the Disposition of Daytime Auroral Ionization in Space—R. L. Leadabrand. (*J. Geophys. Res.*, vol. 66, pp. 421–428; February, 1961.) Radio auroras are classified into two groups according to latitude spread. The properties are compared and their relation to "diffuse" and "discrete" auroras is discussed.

551.594.5:621.396.96 1857
The Slant E_s Echo—a High-Frequency Auroral Echo—H. F. Bates. (*J. Geophys. Res.*, vol. 66, pp. 447–454; February, 1961.) The slant E_s echo is associated with VHF auroral echoes. It is formed by scattering from randomly distributed field-aligned irregularities and is enhanced by least-time focusing and aspect focusing.

551.594.5:621.396.96 1858
Temporal Variations of Auroral Radio-Echo Activity in Subauroral Latitudes—C. D. Watkins. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 140–148; March, 1961.) The diurnal, 27-day, seasonal and 11-year variations in the occurrence of radio auroras are investigated and also the time delay between class-3 flares and the appearance of auroras is measured. The bimodal diurnal distribution may be a consequence of the specular reflection properties of the auroral echoes.

551.594.5:621.396.96:550.386 1859
Auroral Radio Echoes and Magnetic Disturbances—C. D. Watkins. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 131–139; March, 1961.) The occurrence of radio echoes from aurora is strongly correlated with local K-index. The position and motion of individual echo regions

correspond closely with the current systems causing magnetic disturbances.

551.507.362:061.3 1860
Space Research [Book Review]—H. Kallman Bijl, Ed., Interscience Publishers, Inc., New York, N. Y., 1195 pp., 1960, $24.00. (*J. Atmos. Terr. Phys.*, vol. 20, p. 222; March, 1961.) It contains the text, mainly in English, of the scientific papers presented at the First Internatl. Space Science Symp., Nice, France, January, 1960.

551.510.535(084) 1861
An Atlas of Oblique-Incidence Ionograms [Book Review]—V. Agy, K. Davies, and R. Salaman. U. S. Department of Commerce, Washington, D. C., $2.25. (*J. Res. NBS.*, vol. 65D, pp. 35–36; January/February, 1961.) The atlas is published as NBS Technical Note No. 31 (1959) and contains routine records for the paths: a) Washington–St. Louis, b) Washington–Boulder. A discussion of equipment is given, and seasonal variation, layer formation and disappearance, spread echo, MUF extension and other phenomena are illustrated.

LOCATION AND AIDS TO NAVIGATION

621.396.933 1862
A New Assessment of the Gee System—D. H. R. Archer. (*Brit. Commun. Electronics*, vol. 8, pp. 272–275; April, 1961.) Possible applications of the Gee System to long-range navigation and as a basis for a navigation system for areas where the air traffic is dense are discussed in general terms.

621.396.944 1863
Reception and Direction Finding of Electromagnetic Waves in Sea-Water—G. Ziehm. (*Telefunken Ztg.*, vol. 33, pp. 141–150; June, 1960. English summary, pp. 158–159.) VLF wave propagation in sea-water and the limits set to reception by atmospherics and receiver noise at various depths of submersion are discussed. Formulas are derived for the depths at which reception or direction finding is possible, and maximum depths are calculated as a function of transmitter-receiver distance for given transmitter and receiver characteristics.

621.396.96 1864
Radar Picture Transmission—(*Telefunken Ztg.*, vol. 32, pp. 152–181; September, 1959.) English summaries, pp. 208–210.) The following three papers deal with underlying theory including bandwidth compression and the principles of storage-tube design; four such storage tubes are described and details are given of an experimental system.

1) **Principles and Fundamental Problems**—F. Schröter, pp. 152–161.

2) **Storage Tubes**—J. E. Otto and W. Schaffernicht, pp. 162–173.

3) **Frequency-Band Compression of Radar Signals by means of a Line Storage Tube with Circular Deflection of the Electron Beam**—K. Dinter, pp. 174–181.

621.396.96 1865
Technique for Amplitude Modulating a Van Atta Radar Reflector—L. H. Bauer. (Proc. IRE, vol. 49, pp. 634–635; March, 1961.) By introducing phase shifts in the interconnecting lines of a Van Atta array, the radar return can be modulated in amplitude electronically.

621.396.963.3 1866
Combining Remote Radars on a Central Display—G. E. Martin. (*Electronics*, vol. 34, pp. 124–125; February 17, 1961.) Each radar is represented by its own separate sweep on the combined PPI display.

621.396.963.3:621.385.832 1867
Practical Tubes for Bright Radar Displays—Veith. (See 2054.)

621.396.969.3 1868
Techniques and Problems of Tracking Radar—A. F. Braun. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 689–700; July 16, 1960.) The operating principles of various types of radar are summarized. Problems relating to system and equipment design and to operation under various conditions are discussed.

621.396.969.3 1869
Automatic Beacon Radar Identifies Aircraft—W. L. Woodson. (*Electronics*, vol. 34, pp. 57–61; February 10, 1961.) An automatic aircraft interrogation system using airborne transponders is described.

621.396.969.3 1870
A Radar Observation of a Sea-Breeze Front—E. Eastwood and G. C. Rider. (*Nature*, vol. 189, pp. 978–980; March 25, 1961.) The length and penetration inland of a sea-breeze front have been studied using a 23-cm radar and a photographic time-compression technique. It is probable that both birds and refractive discontinuities contributed to mark the passage of the front.

MATERIALS AND SUBSIDIARY TECHNIQUES

535.215:537.311.33 1871
Determination of Recombination Constants from the Spectral Characteristic of a Photocell with a *p-n* Junction—V. K. Subashiev. (*Fiz. Tverdogo Tela*, vol. 2, pp. 205–212; February, 1960.)

535.215:546.4'682'221 1872
Photoconductivity in Ternary Sulphides—J. A. Beun, R. Nitsche and M. Lichtensteiger. (*Physica*, vol. 26, pp. 647–649; August, 1960.) Measurements on $ZnInS_4$, $CdIn_2S_4$ and $HgInS_4$ are reported.

535.215:546.47'221 1873
The Photovoltaic Effect in Striated ZnS Single Crystals—W. J. Merz. (*Helv. Phys. Acta*, vol. 31, pp. 625–635; October 31, 1958.) The photovoltaic effect was investigated as a function of wavelength, light intensity and temperature. A band model is proposed which provides a qualitative explanation of experimental results.

535.215:546.48'221 1874
Processes Prior to Electrical Breakdown in CdS Sing e Crystals—K. W. Böer and U. Kummel. (*Z. angew. Phys.*, vol. 12, pp. 241–244; June, 1960.) The various stages of breakdown due to thermal effects and high field strengths are discussed and illustrated by photographs obtained with the aid of electo-optical techniques [1636 of 1960 (Böer, *et al.*)].

535.215:546.48'221 1875
A Contribution to the Clarification of the Spectral Distribution of the Photoconductivity CdS Single Crystals—H. Berger, H. W. Böer, and E. H. Weber. (*Mber. dtsch. Akad. Wiss. Berlin*, vol. 2, no. 2, pp. 95–101; 1960.) An interpretation is given of the results of photoconductivity measurements in the region of the absorption edge at room temperature, in which three maxima are usually obtained. See also 1904 of 1959 (Böer and Gutjahr).

535.215:546.48'221 1876
Anomalous Photovoltaic Effect of CdS Single Crystals—S. Ibuki, H. Komiya and H. Yamashita. (*J. Phys. Soc. Japan*, vol. 15, p. 2356; December, 1960.) Photo-voltaic effects observed in a CdS crystal partly coated with an evaporated Cu layer are explained as a combination of *p-n* junction action and electron diffusion.

535.215:546.48'221:539.23 1877
Effect of Oxygen upon Sintered Cadmium Sulphide Photoconducting Films—S. Kitamura. (*J. Phys. Soc. Japan*, vol. 15, pp. 2343–2350; December, 1960.)

535.215:546.682'86 1878
Photosensitivity Spectrum Distribution of *p*-Type Indium Antimonide—D. N. Nasledov, M. P. Pronina and Yu. S. Smetannikova. (*Fiz. Tverdogo Tela*, vol. 2, pp. 239–241; February, 1960.) A note of measurements of photoconductivity and photomagnetic effect in *p*-type samples with acceptor concentrations from 10^{13} to $10^{15}/cm^3$ is given.

535.215:546.817'221 1879
On the Temperature Dependence of the Photoconductive Decay Time of Films of the Lead Salts—F. M. Klaassen, J. Blok, H. C. Booy, and F. J. De Hoog. (*Physica*, vol. 26, pp. 623–628; August, 1960.) A comparison of theory with results of measurements on PbS photodetectors indicates that minority carriers are retrapped repeatedly before recombination occurs.

535.37:537.311.3 1880
The Relation between the Recombination Luminescence and Conductivity under Non-isothermal Conditions—K. K. Rebane. (*Fiz. Tverdogo Tela*, vol. 2, pp. 273–274; February, 1960.)

535.37:546.47'221 1881
Electronic Structure of the Centres in ZnS—J. L. Birman. (*Phys. Rev.*, vol. 121, pp. 144–145; January 1, 1961.)

535.37:546.47'221 1882
Vapour-Phase Growth and Properties of Zinc Sulphide Single Crystals—H. Samelson. (*J. Appl. Phys.*, vol. 32, pp. 309–317; February, 1961.)

535.376 1883
Surface Recombination and Diffusion Processes in Cathodoluminescence and Electron-Bombardment-Induced Conductivity—G. Gergely. (*J. Phys. Chem. Solids*, vol. 17, pp. 112–116; December, 1960.) Values of diffusion length and surface recombination velocity are obtained from an analysis of experimental brightness/voltage curves.

535.376:546.47'221 1884
Electroluminescence of Zinc Sulphide Single Crystals—I. T. Steinberger, V. Bar, and E. Alexander. (*Phys. Rev.*, vol. 121, pp. 118–124; January 1, 1961.) Rectangular voltage pulses were applied to single crystals of ZnS. During the ON period the emission gradually increased to a stationary level. Removal of the voltage resulted in a burst of emission which decayed slowly. A model is suggested which explains this behavior.

535.376:546.48'221 1885
Electroluminescence of CdS Single Crystal—H. Yamashita, S. Ibuki, M. Yoshizawa, and H. Komiya. (*J. Phys. Soc. Japan*, vol. 15, p. 2366; December, 1960.) A description and possible explanation of electroluminescence observations is given.

535.376:546.681'18 1886
Electroluminescence of Gallium Phosphide Crystals—F. G. Ullman. (*Nature*, vol. 190, pp. 161–162; April 8, 1961.) Results obtained with crystals of GaP weakly doped with Zn corroborate the observations of Wolff, *et al.* (1433 of 1956).

537.227 1887
Thermal Conduction in Ferroelectric Ceramics—I. Yoshida. (*J. Phys. Soc. Japan.*, pp. 2211–2219; December, 1960.) Measurements on Pb, Ba, and Sr titanates and on Pb zirconate are described and discussed in relation to crystal structure.

537.227:546.431'824–31 1888
On the Origin of Barkhausen Pulses in BaTiO.—R. C. Miller. (*J. Phys. Chem. Solids*, vol. 17, pp. 93–100; December, 1960.) The domain phenomena which give rise to ferroelectric Barkhausen pulses in $BaTiO_3$ have been investigated experimentally: specific domain phenomena have been correlated with particular Barkhausen pulse shapes.

537.227:621.318.57 1889
The Reversal of the Spontaneous Polarization in Guanidine Aluminium Sulphate Hexahydrate—E. Fatuzzo. (*Helv. Phys. Acta*, vol. 33, pp. 429–436; August 15, 1960.) Crystals have been subjected to electrical and thermal treatment and their switching properties studied under different conditions. These properties may, with some additional assumptions, be described by the model developed by Fatuzzo and Merz (1267 of 1960) for triglycine sulphate. At high electric fields the domain-wall motion time is longer than the nucleation time and hence controls the switching process.

537.311.3:538.21 1890
The Relation between Magnetism and Electrical Conductivity of Compounds with Transition Elements—F. Hulliger. (*Helv. Phys. Acta*, vol. 32, pp. 615–654; December 31, 1959. In German.) A detailed review and discussion are given of theoretical and experimental results. Over 100 references.

537.311.31:538.63 1891
Transverse-Even Voltage: a High-Field Galvanomagnetic Effect associated with Open Orbits in Metals—J. R. Klauder and J. E. Kunzler. (*Phys. Rev. Lett.*, vol. 6, pp. 179–182; February 15, 1961.) The shape of the Fermi surface and the open orbit directions can be determined by measurements in single-copper crystals of even voltages transverse to the current when H is also transverse.

537.311.33+535.215 1892
Carrier Density Fluctuations in Semiconductors and Photoconductors with One Kind of Trapping Centres—F. M. Klaassen, K. M. Van Vliet, and J. Blok. (*Physica*, vol. 26, pp. 605–617; August, 1960.) Expresssions for the matrix elements of carrier density fluctuations and for relaxation times are given.

537.311.33 1893
Volume-Controlled, Two-Carrier Currents in Solids: the Injected Plasma Case—M. A. Lampert and A. Rose. (*Phys. Rev.*, vol. 121, pp. 26–37; January 1, 1961.) Double injection into semiconductors and insulators is studied under conditions where the injected electrons and holes are free. The current is field-driven and volume-controlled. The analysis shows an extended voltage region following the Ohm's law region, over which the current is proportional to the voltage squared. In this region the current is depressed through the increase in the number of minority carriers in thermal equilibrium. This is shown to result from recombination kinetics.

537.311.33 1894
Hydrogen-Like Impurity States in Axially Symmetric Crystals—R. W. Keyes. (*IBM J. Res. & Dev.*, vol. 5, pp. 65–66; January, 1961.)

537.311.33 1895
Influence of Interelectronic Collision on Hall Mobility in Nonpolar Semiconductors—Y. Uchiyama. (*Progr. Theor. Phys.*, vol. 24, pp. 455–456; August, 1960.) The correction due to the interelectronic collision is found to be very small in magnitude.

537.311.33 1896
Structure of the Energy Bands in Semiconductors of the $CdIn_2Se_4$ Type—A. I. Gubanov and F. M. Gashimzade. (*Fiz. Tverdogo Tela*, vol. 2, pp. 255–260; February, 1960.)

537.311.33 1897
Semiconduction in $Li_xNi_{(1-x)}O$—S. van Houten. (*J. Phys. Chem. Solids*, vol. 17, pp. 7–17; December, 1960.) NiO is an insulator which may be made conducting by the addition of LiO. An energy level scheme which explains this behavior is discussed.

537.311.33 1898
Current/Voltage Characteristics of Forward-Biased Long *p-i-n* Structures—R. D. Larrabee. (*Phys. Rev.*, vol. 121, pp. 37–39; January 1, 1961.) The characteristics have been observed in several Ge *p-i-n* structures in which the *n* side was biased negatively and the *p* side positively so as to cause a double injection of electrons and holes.

537.311.33:53.082.7 1899
Thermoelectrically Cooled Probe for the Determination of Semiconductor Type—R. V. Jeanes and K. E. G. Pitt. (*J. Sci. Instr.*, vol. 38, p. 33; January, 1961). A simple Bi_2Te_3 cold-probe device is described for the determination of semiconductor type in a near-intrinsic Ge sample. Because the probe is at a lower temperature than the sample there is no risk of heat transfer and subsequent type inversion typical of the hot-probe method.

537.311.33:535.215 1900
Bulk Photoeffects in Inhomogeneous Semiconductors—C. D. Cox. (*Canad. J. Phys.*, vol. 38, pp. 1328–1342; October, 1960.) Theoretical expressions are derived for the relation between photo-EMF and illumination, and between photo-EMF and resistance decrease. Experimental results for Ge filaments are given.

537.311.33:537.312.9 1901
Effect of High Pressure on Electrical Properties of NiO, CoO, CuO and Cu_2O—A. P. Young, W. B. Wilson, and C. M. Schwartz. (*Phys. Rev.*, vol. 121, pp. 77–82; January 1, 1961.)

537.311.33:537.32 1902
Thermoelectric Behaviour of *p-n* Junctions—M. Cutler. (*J. Appl. Phys.*, vol. 32, pp. 222–227; February, 1961.) Equations are derived for the flow of carriers and electronic heat when a temperature difference and a potential difference exist across a *p-n* junction. Large- and small-signal situations are discussed.

537.311.33:538.569.4 1903
A Note on Date's Paper "Magneto-plasma Resonance in Semiconductors: Part 1"—K. Yamagata. (*J. Phys. Soc. Japan*, vol. 15, p. 2363; December, 1960.) Comment is given on 931 of March considering the effect of anisotropic mass on magneto-plasma resonance.

537.311.33:538.63 1904
Galvanomagnetic Effects and their Application—C. Hilsum. (*Brit. J. Appl. Phys.*, vol. 12, pp. 85–91; March, 1961.) The properties of semiconductors suitable for galvanomagnetic applications are discussed and instruments based on the Hall effect and magnetoresistance are described.

537.311.33:546.23 1905
Dielectric Investigations of Polycrystalline Selenium—W. Ludwig. (*Mber. dtsch. Akad. Wiss. Berlin*, vol. 2, no. 2, pp. 91–92; 1960.) A brief note is given on results of ac bridge measurements on Br-doped high-purity Se at temperatures in the range $+40°$ to $-160°C$.

537.311.33:[546.28+546.289 1906
The Temperature Dependence of the Polarizability of the Free Carriers in Germanium and Silicon—M. Cardona, W. Paul, and H. Brooks. (*Helv. Phys. Acta*, vol. 33, pp. 329–346; August 15, 1960.) The contribution of the free carriers to the total electric polarizability was determined from the reflectivity and an average effective mass for the carriers was deduced. An increase in electron mass with both carrier concentration and temperature was found in both *n*-type Ge and *n*-type Si. No definite conclusions could be drawn about *p*-type Ge owing to transitions between branches of the degenerate valence band. For *p*-type Si the effective mass increases with temperature.

537.311.33:[546.28+546.289 1907
Theory of Solubility of Interstitial Impurities in Germanium and Silicon—K. Weiser. (*J. Phys. Chem. Solids*, vol. 17, pp. 149–161; December, 1960.) A theory of solubility is developed which is based on estimating the change in energy and in entropy when an impurity is placed in an interstitial site in the lattice.

537.311.33:[546.28+546.289]:535.215 1908
Photoelectron Emission from Germanium and Silicon in the Amorphous and Crystalline States—P. G. Borzyak, L. S. Miroshnichenko, and O. G. Sarbeĭ. (*Fiz. Tverdogo Tela*, vol. 2, pp. 314–318; February, 1960.) The spectral sensitivity curve for crystalline Ge shows a dip in the short-wavelength region which is not observed with amorphous films. This effect is less marked in the case of Si.

537.311.33:[546.28+546.289]:539.23 1909
The Preparation of Thin Films of Germanium and Silicon—B. A. Irving. (*Brit. J. Appl. Phys.*, vol. 12, pp. 92–93; March, 1961.) Films about 1000 Å thick, suitable for observing dislocations by transmission electron microscopy, have been prepared from the brittle semiconductors germanium and silicon by a combination of mechanical polishing and chemical etching.

537.311.33:546.28 1910
Surface States on Cleaved Silicon—D. R. Palmer, S. R. Morrison and C. E. Dauenbaugh. (*Phys. Rev. Lett.*, vol. 6, pp. 170–171; February 15, 1961.)

537.311.33:546.28 1911
Acoustic-Mode Mobilities for 'Split *p*-Silicon'—P. J. Price and Y. H. Kao. (*IBM J. Res. & Dev.*, vol. 5, pp. 63–64; January, 1961.)

537.311.33:546.28 1912
Spin Resonance of Electrons on Donors in *p*-type Silicon—G. Bemski and B. Szymanski. (*J. Phys. Chem. Solids*, vol. 17, pp. 173–175; December, 1960.) The resonance was observed using compensated *p*-type Si crystals after the samples had been illuminated with light of about 1 $\mu\lambda$. The amplitude of the resonance gives useful information on the concentration of the donor.

537.311.33:546.28 1913
The Effect of Gold on the Electrical Properties of Silicon—B. I. Boltaks, G. S. Kulikov, and R. Sh. Malkovich. (*Fiz. Tverdogo Tela*, vol. 2, pp. 181–191; February, 1960.) Donor and acceptor levels determined from Hall-effect measurements agree with those reported by Collins, *et al.* (2498 of 1957). Experimental and calculated values of resistivity and carrier concentration in gold-alloyed samples of *n*- and *p*-type Si with different initial resistivity are compared. A nomogram for calculating the resistance of gold-alloyed samples is given.

537.311.33:546.28:535.34–15 1914
The Absorption of Infrared Radiation by Free Charge Carriers in Silicon—V. S. Vavilov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 374–377; February, 1960.) Measurements have been made in

the wavelength range 1–11 μ on single-crystal p- and n-type Si with carrier concentration between 10^{14} and 5×10^{17} cm^{-3}, and on samples with carrier concentration 10^{12} cm^{-3} irradiated with fast neutrons. For highly transparent crystals the λ^{1-5} relation for the absorption coefficient was not confirmed.

537.311.33:546.289 1915
Pressure Dependence of the Direct Energy Gap in Germanium—M. Cardona and W. Paul. (*J. Phys. Chem. Solids*, vol. 17, pp. 138–142; December, 1960.) "The pressure dependence of the energy gap corresponding to allowed optical transitions in Ge has been measured at room temperature and pressures up to 7000 kg/cm^2. This direct energy gap is found to increase at a rate of $1.3\pm0.1\times10^{-5}$ eV.cm^2/kg, in agreement with previous approximate determinations and with the pressure coefficient of the same energy gap in group III-V compounds."

537.311.33:546.289 1916
Direct Viewing of Imperfections in Germanium p-n Junctions—M. Tomono. (*J. Phys. Soc. Japan*, vol. 15, pp. 2254–2264; December, 1960.) A copper-plating method is described for making junction imperfections visible. The imperfections are then related to the reverse (electrical) characteristics of the junction.

537.311.33:546.289 1917
Investigation of the Effect of Certain Factors on Formation of Dislocations during Crystallization and on the Dislocation States in Germanium Single Crystals—A. D. Belyaev, V. N. Vasilevskaya, and E. G. Miselyuk. (*Fiz. Tverdogo Tela*, vol. 2, pp. 227–234; February, 1960.) Dislocations dispersed between boundaries of regions with different orientation are displaced toward these boundaries by annealing at 700 800°C. Dislocations at these boundaries are removed only at temperatures close to the melting point. The effect of dislocations of density from 10^3 to 10^7 cm^{-2} on carrier lifetime is determined.

537.311.33:546.289 1918
The Effect of Lead Treatment of Germanium on the Lifetime of Nonequilibrium Charge Carriers—A. K. Mednikov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 235–238; February, 1960.) The diffusion length of minority carriers substantially decreased with the removal of residual Cu from Ge by treatment with molten lead. Increasing the Cu concentration caused the diffusion length first to increase and then to decrease.

537.311.33:546.289 1919
Electron-Electron Interaction in Hot-Electron Problems—J. Yamashita. (*Prog. Theoret. Phys.*, vol. 24, pp. 357–369; August, 1960.) The theory of warm and hot electrons in n-type Ge at 77°K is discussed with reference to Gunn's experiments (*J. Phys. Chem. Solids*, vol. 8, pp. 239–241; January, 1959).

537.311.33:546.289 1920
Donor Concentration at the Surface of a Diffused n-Type Layer on p-Type Germanium—R. Glang and W. B. Easton. (*J. Electrochem. Soc.*, vol. 107, pp. 758–763; September, 1960.) Four methods of evaluating donor concentration have been investigated. All methods assume a complementary error function distribution in the diffused layer and require the use of experimental and published data. With three of the methods, calculated surface concentrations agree within a factor of 2 or 3.

537.311.33:546.289:535.215 1921
Current/Voltage Characteristics of Photoelectric Emission from Germanium—P. G. Borzyak, P. M. Marchuk, and O. G. Sarbeĭ. (*Fiz. Tverdogo Tela*, vol. 2, pp. 306–313; February, 1960.) Experimentally determined I/V characteristics of the emission from Ge films with low work function show no evidence of a bulk photoeffect.

537.311.33:546.3–1'289'28 1922
Electrical Conductivity and Hall Effect of Ge-Si Alloys—G. Busch and O. Vogt. (*Helv. Phys. Acta*, vol. 33, pp. 437–458; August 15, 1960. In German.) Methods of preparation of Ge-Si single-crystal and polycrystalline alloys are described. Hall coefficients and conductivity have been measured in the temperature range 20° 900°C, and electron and hole mobilities and intrinsic carrier concentrations calculated as functions of alloy composition. Typical results are given and discussed.

537.311.33:546.3–1'289'28 1923
Indirect Transition in Narrow Junction of Ge-Si Alloy—K. Ando. (*J. Phys. Soc. Japan*, vol. 15, p. 2360; December, 1960.) Data on indirect transitions are obtained from cusps in junction characteristics measured at liquid helium temperature.

537.311.33:[546.55'221+546.55'231 1924
Relations between the Crystalline Structure and the Electronic Properties of Ag_2S, Ag_2Se, Cu_2Se Compounds—P. Junod. (*Helv. Phys. Acta*, vol. 32, pp. 567–600; December 31, 1959. In French.)

537.311.33:[546.571'221+546.571'231 1925
Brillouin Zones, Chemical Bonds and Conduction Mode of Ag_2S and Ag_2Se—P. Junod. (*Helv. Phys. Acta*, vol. 32, pp. 601–614; December 31, 1959. In French.)

537.311.33:546.681'19 1926
Scattering of Current Carriers in Gallium Arsenide in the Presence of Strong Degeneracy—O. V. Emel'yanenko, T. S. Lagunova and D. N. Nasledov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 192–197; February, 1960.) Results of conductivity and Hall-effect measurements on GaAs samples with n- and p-type impurity conductivity show that the mobility of electrons and holes depends only weakly on the concentration of uncompensated impurities.

537.311.33:546.681'682'19 1927
Electrical and Optical Properties of GaAs-InAs Alloys—J. C. Woolley, C. M. Gillett, and J. A. Evans. [*Proc. Phys. Soc. (London)*, vol. 77, pp. 700–704; March 1, 1961.] Electrical measurements showed that there is mixed conduction in the alloys and hence the Hall mobility is without significance. Optical transmission measurements of optical energy gap give good agreement with values obtained by diffuse-reflection methods.

537.311.33:546.681'682'86 1928
Electrical Properties of GaSb-InSb Alloys—J. C. Woolley and C. M. Gillett. (*J. Phys. Chem. Solids*, vol. 17, pp. 34–43; December, 1960.) The electrical properties have been investigated as a function of composition. Values of extrapolated thermal energy gap, electron mobility and mobility ratio have been determined for some 25 specimens.

537.311.33:546.682'86 1929
Orientation-Dependent Distribution Coefficients in Melt-Grown InSb Crystals—J. B. Mullin and K. F. Hulme. (*J. Phys. Chem. Solids*, vol. 17, pp. 1–6; December, 1960.)

537.311.33:546.682'86 1930
Carrier Lifetime in Indium Antimonide—R. A. Laff and H. Y. Fan. (*Phys. Rev.*, vol. 121, pp. 53–62, January 1, 1961.) The recombination of excess electron-hole pairs in InSb has been studied in the temperature range 200°K–15°K where it is controlled by localized centers. A model for the process is deduced from the analysis of the results, and evidence is obtained that the recombination centers are due to structural defects.

537.311.33:546.682'86:538.63 1931
Galvanomagnetic Effects in Three-Band Semiconductors—Experiments with p-Type InSb—G. Fischer. (*Helv. Phys. Acta*, vol. 33, pp. 463–488; August 15, 1960.) A three-band model is discussed and formulas are given with which it is possible to derive values for the concentrations and mobilities of the various charge carriers from the dependence of the Hall coefficient and resistivity on the magnetic field. This model appears valid for p-type InSb in the extrinsic range.

537.311.33:546.817'241:538.63 1932
Oscillatory Magnetoresistance in n-Type PbTe—C. D. Kuglin, M. R. Ellett, and K. F. Cuff. (*Phys. Rev. Lett.*, vol. 6, pp. 177–179; February 15, 1961.)

537.312.62 1933
Magnetic-Field Dependence of Energy Gap in Superconductors—K. K. Gupta and V. S. Mathur. (*Phys. Rev.*, vol. 121, pp. 107–117; January 1, 1961.) The dependence of the energy gap on static magnetic fields has been derived in a gauge-invariant way from the theory of Bardeen, *et al.* (1386 of 1958). The gap decreases with magnetic field approaching the critical value. Optimum conditions for observation of this effect are discussed.

537.312.62:538.63 1934
Superconductivity in Nb_3Sn at High Current Density in a Magnetic Field of 88 KG—J. E. Kunzler, E. Buehler, F. S. L. Hsu, and J. H. Wernick. (*Phys. Rev. Lett.*, vol. 6, pp. 89 91; February 1, 1961.) Results of observations indicate that superconducting solenoid magnets with fields of 100 kG are feasible.

538.1/.2:061.3 1935
International Colloquim on Magnetism—(*J. Phys. Radium*, vol. 20, pp. 65–442; February/March, 1959.) The text is given of papers presented and subsequent discussions at the colloquim held in Grenoble, France, July 2nd–6th, 1958. 78 papers were presented, of which 44 were in English.

538.22:537.27 1936
Magnetoelectric Effect in Antiferromagnetics—D. N. Astrov. (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 984–985; March, 1960.) A note on measurements of the magnetic moment developed in a sample of Cr_2O_3 in an alternating electric field is given. Curves show the temperature dependence of a signal at the output of a measuring amplifier with fields of 230 and 430 v/cm at 10^4 cps.

538.221 1937
Anisotropy on Polycrystalline Sheets of V-Permendur—C. Kuroda. (*J. Phys. Soc. Japan*, vol. 15, p. 2355; December, 1960.)

538.221 1938
The Anisotropy Constants of Ferromagnetic Cubic Crystals—A. S. Viglin. (*Fiz. Tverdogo Tela*, vol. 2, pp. 331–346; February, 1960.) A numerical treatment relating to calculations of anisotropy energy is given.

538.221 1939
On the Mechanism of Reversible Appearance of Residual Magnetization at Low Temperature Transition in αFe_2O_3—K. Siratori, A. Tasaki, and S. Iida. (*J. Phys. Soc. Japan*, vol. 15, pp. 2357–2358; December, 1960.)

538.221:539.23 1940
Depictive Representation of the Coherent Rotation of Magnetization in Thin Ferromagnetic Films—E. Feldtkeller. (*Z. angew. Phys.*, vol. 12, pp. 257–261; June, 1960.) De-

tails of the magnetic reversal process in thin films are discussed and a graphical method is given for determining the direction and rate of change of magnetization at any instant on the basis of the directional characteristics of magnetization energy.

538.221:539.23:537.312.8 1941
Influence of a Magnetic Field on the Electrical Resistance of Thin Ferromagnetic Layers at Low Temperatures—A. A. Hirsch. (*Physica*, vol. 25, pp. 581–589; July, 1959.)

538.221:621.318.124 1942
The Thermomagnetic Behaviour of Cobalt Ferrite—L. F. Bates and A. Pacey. [*Proc. Phys. Soc., (London)*, vol. 77, pp. 567–575; March 1, 1961.] The behavior is similar to that of other materials; a new method of analysis of results is described.

538.221:621.318.134 1943
Low-Loss Ferrites used in Electronics and Telecommunications—Y. Lescroel and A. Pierrot. [*Câbles & Trans.* (Paris), vol. 14, pp. 220–244; July, 1960.] The effects of manufacturing procedure and, in particular, conditions of heat treatment on the permeability and loss factors of Mn-Zn and Ni-Zn ferrites are investigated.

538.221:621.318.134 1944
Manganese-Zinc Ferrites with Spontaneous Isoperm Loop—M. Kornetzki, E. Moser, and E. Rösss. (*Naturwiss.*, vol. 47, p. 274; June, 1960.) The magnetization curve of a magnetically isotropic ferrite of composition $Mn_{0.46}Zn_{0.47}Fe_{0.07}O \cdot Fe_2O_3$ is given; the probable causes of the isoperm characteristic are discussed.

538.221:621.318.134 1945
Spontaneous Magnetization of Magnesium Ferrite—Manganite System—K. Muramori and S. Miyahara. (*J. Phys. Soc. Japan*, vol. 15, p. 2354; December, 1960.)

538.221:621.318.134 1946
Interpretation of the Characteristics of Microwave Ferrites by means of the Forced Precession of Gyroscopes—H. Lueg. (*Telefunken Ztg.*, vol. 33, pp. 132–140; June, 1960. English summary, p. 158.) The use of a gyroscope is proposed as an analog of the gyromagnetic properties of ferrites. The validity of the method is checked using results of ferrite measurements by other authors.

538.221:621.318.134 1947
The Irreversible Change of Magnetization produced in 'Square-Loop' Ferrite by Pulsed Magnetic Fields—J. E. Knowles. [*Proc. Phys. Soc., (London)*, vol. 77, pp. 576–586; March 1, 1961.] The experimental results were interpreted in terms of a domain wall model; it was found that the domain wall energy passed through a maximum 25 times in the course of a magnetization reversal.

538.221:621.318.134:538.569.4 1948
Note on Ferromagnetic Relaxation Equations—H. Suhl and R. C. Fletcher. (*J. Appl. Phys.*, vol. 32, pp. 281–282; February, 1961.) The omission of an explicit back-reaction term in "energy" and "number of quanta" formulations is justified provided a large number of spin waves are excited by the scattering centers.

538.221:621.318.134:538.569.4 1949
Suppression of Subsidiary Absorption in Ferrites by Modulation Techniques—T. S. Hartwick, E. R. Peressini, and M. T. Weiss. (*Phys. Rev. Lett.*, vol. 6, pp. 176–177; February 15, 1961.) The prediction of Suhl (1807 above) is confirmed by experiments on Y-Fe garnet. Optimum modulation frequencies of about 1 Mc are found, depending upon the excess of the microwave field above normal threshold.

538.221:621.318.134:538.569.4 1950
Ferromagnetic Resonance in Europium-Iron Garnet—T. Miyadai. (*J. Phys. Soc. Japan*, vol. 15, pp. 2205–2210; December, 1960.) A study of g-values and line widths of single-crystal and polycrystalline specimens at 18 Gc and at temperatures from 100°K to the Curie point (565°K) is given.

538.222:534.283–8 1951
Selection Rule for the Interaction of Microwave Ultrasonics with Spins—N. S. Shiren and E. B. Tucker. (*Phys. Rev. Lett.*, vol. 6, pp. 105–106; February 1, 1961.)

538.222:543.283–8 1952
Attenuation of Longitudinal Ultrasonic Vibrations by Spin-Photon Coupling in Ruby—E. B. Tucker. (*Phys. Rev. Lett.*, vol. 6, pp. 183–185; February 15, 1961.) The magnetoelastic coupling constant is determined from the observed attenuation. See 1951 above.

538.222:538.569.4 1953
Spin-Lattice Relaxation in Chromium Corundum—A.A. Manenkov and A.M. Prokhorov. (*Zh. Eksp. Teor. Fiz.*, vol. 38, pp. 729–733; March, 1960.)

538.222:538.569.4 1954
Relaxation in Ruby—R. A. Armstrong and A. Szabo. (*Canad. J. Phys.*, vol. 38, pp. 1304–1317; October, 1960.) "The relaxation of the (1↔2) and (2↔3) transitions in chrome-doped Al_2O_3 (0.015%) has been studied at S-band frequencies, using a pulsed microwave method, over a range of crystal orientations in the magnetic field at temperatures of 77°K to 50°K, and at 4.2°K and 1.6°K."

621.315.6:538.569.3 1955
Electromagnetic Properties of Insulators: Part 2—V. Ambegaokar. (*Phys. Rev.*, vol. 121, pp. 91–103; January 1, 1961.) The system considered is an insulator plus one electron. The main result is that the response of the system to low-frequency electric fields is exactly that of a free electron with a certain effective mass moving in a medium having the dielectric constant of a perfect insulator. Part 1: 2468 of 1960 (Ambegaokar and Kohn).

621.315.61:539.23 1956
Tunnelling through Thin Insulating Layers—J. C. Fischer and I. Giaever. (*J. Appl. Phys.*, vol. 32, pp. 172–177; February, 1961.) Measurements of the tunneling current through thin Al oxide films can be formally explained by a theory of Holm (2455 of 1951), provided an electron mass factor of 1/9 is used.

MEASUREMENTS AND TEST GEAR

621.3.018.41(083.74) 1957
The Significance of the Time Intervals arranged in Geometric Progression for the Standard-Frequency and Time-Signal Transmission of the Physikalisch-Technishe Bundesanstalt via Station DCF 77—U. Adelsberger. (*Nachtech. Z.*, vol. 13, pp. 296 298; June, 1960.) The usefulness of the time intervals of 2 minutes and 3 hours forming the basis of the transmission schedule and their relation to other useful time intervals are discussed. See also 3977 of 1960 (Süss) and back references.

621.3.018.41(083.74) 1958
Characteristics of the Ammonia Beam Maser (AM-1) as an Atomic Frequency Standard at JJY—Y. Saburi and M. Kobayashi. (*J. Radio Res. Labs. Japan*, vol. 7, pp. 425–436; September, 1960.) The construction of the maser and the associated circuit arrangements are described. Comparisons with time signals emitted from WWVH show that the frequency stability is ± 2 or 3 parts in 10^{10}.

621.317.2:538.566.08+534.844.1 1959
The Upper Limits for the Reverberation Time of Reverberation Chambers for Acoustic and Electromagnetic Waves—Walther. (See 1716.)

621.317.3.029.64:538.632 1960
On the Method of Measuring Hall Coefficient at Microwave Frequencies—K. Yamagata. (*Sci. Rep. Res. Inst. Tohoku Univ., A*, vol. 12, pp. 235–246; June, 1960.) A theory of the bimodal or dual-mode cavity without initial unbalance is developed.

621.317.3.029.64:538.632 1961
Measurement of Hall Mobility of Germanium at a Microwave Frequency—K. Yamagata and T. Fukuroi. (*Sci. Rep. Res. Inst. Tohoku Univ., A* vol. 12, pp. 247–251; June, 1960.) The theory of the dual-mode cavity developed by Yamagata (1960 above) is extended to include the case of initial unbalance, and a report is given of experiments based on a dual-mode cavity with resistive unbalance. The accuracy of measurement of the Hall mobility is limited by the accuracy with which the microwave power level can be measured.

621.317.412 1962
Measurement of Magnetic Susceptibility in Very High Pulsed Fields—R. Stevenson. (*Rev. Sci. Instr.*, vol. 32, pp. 28–31; January, 1961.) The sample is suspended in a nonuniform magnetic field and the force on it when the field changes is measured by a transducer comprising two piezoelectric crystals.

621.317.755:531.76 1963
Zig-Zag Oscilloscope Presentation of Millimicrosecond Accuracy for Microsecond Time Invervals—E. G. Leger, D. Nyberg, K. Graf, and L. Tardif. (*Rev. Sci. Instr.*, vol. 32, pp. 57–61; January, 1961.) The zig-zag wave, the trigger pulses and the time marks 2-mμsec wide at 50-mμsec intervals are derived from a 2-Mc crystal-controlled oscillator; six oscilloscopes can be driven simultaneously or in sequence from delayed triggers.

621.317.794 1964
Cobalt-Manganese Semiconducting Oxide Bolometers—A. L. Burkin and I. T. Sheftel'. (*Fiz. Tverdogo Tela*, vol. 2, pp. 288–296; February, 1960.) Techniques for the measurement of bolometer characteristics are discussed and the design of three types of bolometer as infrared-sensitive devices is described.

621.317.794.029.64/.66:537.312.62 1965
Superconductors as Quantum Detectors for Microwave and Sub-millimetre-Wave Radiation—E. Burstein, D. N. Langenberg, and B. N. Taylor. (*Phys. Rev. Lett.*, vol. 6, pp. 92–94; February 1, 1961.) An analysis of low-voltage tunneling in metal/barrier/superconductor and superconductor/barrier/superconductor structures suggests its application for measuring microwave and submillimeter radiation incident on the barrier region. Limitations due to carrier lifetime are discussed.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

531.78:537.311.33:537.312.9 1966
Semiconductor Strain Gauges offer High Sensitivity—R. E. Talmo. (*Electronics*, vol. 34, pp. 43–45; February 24, 1961.) Single-crystal Si gives a change in resistance 10–100 times greater for a given strain than metallic gauges. See 3230 of 1960 (Geyling and Forst).

531.79:621.397.331.3 1967
An Automatic Particle Counter and Sizer—H. A. Dell, D. S. Hobbs, and M. S. Richards. (*Philips Tech. Rev.*, vol. 21, pp. 253–267; August 4, 1960.) Methods used for automatic counting and sizing are discussed and commer-

cial equipment is described in which the sample is photographed and the film examined automatically using a flying-spot scanning system.

534.88 1968
Narrow-Beam Echo-Ranger for Fishery and Geological Investigations—M. J. Tucker and A. R. Stubbs. (*Brit. J. Appl. Phys.*, vol. 12, pp. 103–110; March, 1961.) A detailed description is given of a 36-kc acoustic echo-ranger with a range of 800 yards suitable for fish detection and geological investigation of the sea bed. Typical records are shown and discussed.

621.362:621.387 1969
A New Thermionic Generator—D. Gabor. (*Nature*, vol. 189, pp. 868–872; March 18, 1961.) The principle of operation of a vacuum diode using argon vapor is described. The main discharge occurs between the emitter and a large-area collector of cellular construction. Ions are supplied to the main discharge space from an auxiliary discharge between a perforated structure and an auxiliary anode. By controlling this auxiliary discharge, direct generation of ac is possible. An experimental cost figure of 0.05–0.1 w/a has been achieved.

621.362:621.387 1970
Low-Frequency Oscillations in a Filamentary-Cathode Cesium Diode Converter—K. P. Luke and F. E. Jamerson. (*J. Appl. Phys.*, vol. 32, p. 321; February, 1961.) Oscillations at frequencies below 100 kc are reported, and waveforms are given. Some of the characteristics correspond to a plasma potential distribution unlike that in high-frequency oscillations.

621.384.611.3 1971
The Design and Construction of a 29-MeV Microtron—D. K. Aitken, F. F. Heymann, R. E. Jennings, and P. I. P. Kalmus. [*Proc. Phys. Soc., (London)*, vol. 77, pp. 769–785; March 1, 1961.] The microton has a 20-ton magnet and a pole diameter of 80 inches. An extracted electron beam of 10^{-8} a at an energy of 29 Mev can be focused to a spot about 2 mm in diameter.

621.384.8 1972
Microwave Separator for High-Energy Particle Beams—P. R. Phillips. (*Rev. Sci. Instr.*, vol. 32, pp. 13–16; January, 1961.) 150-Mev electrons were deflected $\frac{3}{4}$ inch at the final focus of the analyzing magnet, using a TM_{012} rectangular cavity with a Q of 15,000 and maximum power dissipation of 1.3 mw.

621.387.4:621.383 1973
The Measurement of Proton Currents by means of Photosemiconductors and Measurements of Polarization Dependence on Composite Photocathodes—P. Görlich. (*Mber. dtsch. Akad. Wiss. Berlin*, vol. 2, no. 2, pp. 67–70; 1960.)

621.396.969.14 1974
Speed Measurement by means of the Electromagnetic Doppler Effect—B. Koch. (*Arch. tech. Messen*, Nos. 293 and 295, pp. 109–112 and 153–156; June and August, 1960.) Details are given of practical applications, following an outline of the principles underlying Doppler-radar measurement methods. 61 references.

77:537.2(083.74) 1975
I.R.E. Standards on Electrostatographic Devices, 1961—(Proc. IRE, vol. 49, pp. 619–621; March, 1961.) Standard 60 IRE 28.S2 defining terms used.

PROPAGATION OF WAVES

621.391.812.34:551.507.362.2 1976
Observed Field Strength in the Neighbourhood of the Skip Distance—Yeh and Swenson. (See 1837.)

621.391.812.61 1977
Attenuation of Electromagnetic Wave due to Rain with Distorted Raindrops—T. Oguchi. (*J. Radio Res. Labs., Japan*, vol. 7, pp. 467–485; September, 1960.) The scattered field is expressed as a function of the deformation of a drop from spherical shape. The deformation as a function of terminal velocity is known and hence a relation between attenuation and rate of precipitation can be found. Greater attenuation is expected for horizontal polarization.

621.391.812.61.029.65 1978
An Analysis of Recent Measurements of the Atmospheric Absorption of Millimetric Radio Waves—C. W. Tolbert and A. W. Straiton. (Proc. IRE, vol. 49, pp. 649–650; March, 1961.) Water-vapour losses are greatly enhanced near the oxygen absorption lines. See 1813 above.

621.391.812.62.029.62 1979
Observation of F-Layer and Sporadic-E Scatter at V.H.F. in the Far East—K. Miya, T. Sasaki, and M. Ishikawa. (*J. Res. NBS*, vol. 65D, pp. 93–99; January/February, 1961.) Measurements made over the paths Okinawa-Tokyo (1480 km) and Philippines-Tokyo (2850 km) at about 50 Mc are described.

621.391.812.621 1980
Correlation of Monthly Median Transmission Loss and Refractive Index Profile Characteristics—B. R. Bean and B. A. Cahoon. (*J. Res. NBS*, vol. 65D, pp. 67–74; January/February, 1961.) An examination of propagation data taken at 100 Mc over 21 paths in the U.S.A. shows that the surface value of atmospheric refractive index is well correlated with the annual cycle of radio transmission loss.

621.391.812.622.029.64 1981
Characteristics of Maritime Advective Duct and their Effect on the Microwave Propagation Beyond the Line of Sight—A. Takahira and H. Irie. (*J. Radio Res. Labs, Japan*, vol. 7, pp. 531–544; September, 1960.) Helicopters were used to make measurements of atmospheric refractive index over the sea along the radio wave path. It is possible to predict the profile of the M curve over the sea up to 20 km from the coast line.

621.391.812.624.029.63 1982
Correlation between Amplitudes of Radio Waves of Different Frequencies in U.H.F. Beyond-the-Horizon Propagation—M. Hirai, M. Fukushima, and Y. Kurihara. (*J. Radio Res. Labs., Japan*, vol. 7, pp. 509–529; September, 1960.) Selective fading is caused by interference between multipath waves. This is treated theoretically and expressions are derived for the amplitude correlation coefficient, the distribution of amplitude ratios and the distribution of multiple-path delays. A comparison is made between these theoretical formulas and experimental data.

621.391.812.63 1983
Wave Interaction in Plasma Inhomogeneities—L. Wetzel. (*J. Appl. Phys.*, pp. 327–328; February, 1961.) The perturbation of electron density giving rise to first-order combination frequencies [3847 of 1959 (Ginzburg)] is deduced for the case of a spatially homogeneous plasma and compared with the perturbation normally giving rise to second-order wave interaction in a homogeneous plasma.

621.391.812.63 1984
Focusing of Radio Waves Reflected from a Rough Curved Ionosphere—J. D. Whitehead. (*Aust. J. Phys.*, vol. 13, pp. 621–624; December, 1960.) The increase in echo amplitude due to focusing by a rough curved ionosphere is shown to be given by the same formula as that for a smooth ionosphere (see 914 of 1957), but different areas of reflection are effective in the two cases, and as a result large amplitude increases are not expected in the rough case.

621.391.812.63 1985
Perpendicular Intersections with a Dipole Field—M. H. Cohen and M. L. Dwarkin. (*J. Geophys. Res.*, vol. 66, pp. 411–419; February, 1961.) "This paper deals with the geometry of radio rays originating at an arbitrary point in a force-free dipole magnetic field. The echo surface, defined by the points where the rays intersect the field at right angles, is calculated. The distance from the source point to the echo surface is computed and plotted for various configurations."

621.391.812.63 1986
Radio Wave Reflections from the Mesosphere: Part 1—Heights of Occurrence—J. B. Gregory. (*J. Geophys. Res.*, vol. 66, pp. 429–445; February, 1961.) The height distribution of partial reflections from the lower ionosphere was made in Christchurch, New Zealand, for one year using a frequency of 1.75 Mc. Reflections occur most frequently from regions whose lower boundaries are at 86, 74, 66, 61, 55 km. Some small seasonal trends were noticed. The reflections are thought to be due to turbulent scatter in the presence of a gradient of electron density at certain preferred heights.

621.391.812.63:523.78 1987
Behaviour of Broadcast-Frequency Waves at Oblique Incidence during an Annular Eclipse—R. K. MacCrone and F. R. N. Nabarro. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 200–205; March, 1961.) Abrupt increases in received signal strength for oblique incidence are observed during an annular eclipse. The mechanism suggested is a Chapman solar-particle eclipse causing sudden changes in reflection heights from D to E region.

621.391.812.63:551.510.535 1988
On the Evaluation of the Group Refractive Index in Case of No Collisions—H. Unz. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 189–194; March, 1961.) An alternative method of evaluating the group refractive index μ' in magneto-ionic theory is shown. Expressions are derived, simpler than those given, *e.g.*, by Shinn and Whale (1405 of 1951), and particularly suitable for calculating μ and μ' near the reflection point.

621.391.812.63:621.396.677 1989
Launching Over the Sea of Vertically Polarized Waves for Long-Distance Ionospheric Propagation—Willoughby. (See 1733.)

621.391.812.63.029.4 1990
Magneto-ionic Propagation Phenomena in Low- and Very-Low-Radiofrequency Waves Reflected by the Ionosphere—J. R. Johler. (*J. Res. NBS*, vol. 65D, pp. 53–65; January/February, 1961.) An analysis is given illustrating the dependence of the amplitude and phase of the reflected wave upon the direction of propagation relative to the direction of the earth's magnetic field. A plane sharply bounded ionosphere with plane-wave excitation is used. Tables applicable to VLF propagation are given.

621.391.812.63.029.45 1991
A New Approach to the Mode Theory of V.L.F. Propagation—J. R. Wait. (*J. Res. NBS*, vol. 65D, pp. 37–46; January/February, 1961.) Approximate forms of the wave functions appropriate to grazing incidence are introduced which lead to relatively concise results for the influence of the earth's curvature; influence of the earth's magnetic field is also discussed. Numerical results for the attenuation and phase velocity of the dominant mode are given.

621.391.812.63.029.45 1992
East-West Effect on V.L.F. Mode Transmission across the Earth's Magnetic Field—

D. Dobrott and A. Ishimaru. (*J. Res. NBS*, vol. 65D, pp. 47–52; January/February, 1961.) An analysis is given for modes propagating within a parallel-plate waveguide, the lower boundary being a perfect conductor and the upper a sharply defined semi-infinite plasma with a constant magnetic field applied. Some agreement with experimental results is found.

621.391.812.63.029.45 1993
Waveguide-Mode Propagation of Very-Low-Frequency Radio Waves—H. G. Martin. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 206–209; March, 1961.) Theoretical calculations on the E-W asymmetry of VLF wave propagation are given.

621.391.812.63.029.45 1994
Random Fluctuations in Very-Low-Frequency Signals Reflected Obliquely from the Ionosphere—J. K. Hargreaves. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 155–166; March, 1961.) The fluctuations of signals from VLF transmitters at distances of 800 and 6000 km were 0.15 and 1.02, respectively, of the mean amplitude. The results could be explained by a model with constant reflection coefficient but varying height.

621.391.812.63.029.45:523.5 1995
V.L.F. Phase Perturbation associated with Meteor Shower Activity—C. J. Chilton. (*J. Geophys. Res.*, vol. 66, pp. 379–383; February, 1961.) The diurnal phase variations of radio waves from Rugby, England, on 16 kc were measured at Boulder, Colorado. Anomalous phase changes were detected when the Lyrid, Aquarid and Perseid meteor showers occurred but the reasons have not been explained. The height of reflection was approximately 80 km.

621.391.812.631:551.510.535(98) 1996
Statistical Study in the Occurrence of Polar Blackouts—Kasuya. (See 1854.)

621.371:061.3 1997
Electromagnetic Wave Propagation [Book Review]—M. Desirant and J. L. Michiels, Eds., Academic Press, Inc., London, Eng., 730 pp., 1960, 157 s. (*J. Atmos. Terr. Phys.*, vol. 20, pp. 222–223; March, 1961.) The text is given of 54 papers presented at a conference associated with the International Exhibition in Brussels, Belgium, 1958.

RECEPTION

621.376.23 1998
Zeros of a Stationary Random Signal—H. Debart. [*Câbles & Trans.* (Paris), vol. 14, pp. 191–199; July, 1960.] An application is given of the Loeve-Karhunen expansion to the approximate calculation of the probability functions $P_0(t) \cdots P_n(t)$, probabilities for which, in the time interval t, there will be a prescribed number of zero crossings.

621.376.23:621.372.54 1999
Self-Adaptive Filter finds Unknown Signal in Noise—C. V. Jakowatz and G. M. White. (*Electronics*, vol. 34, pp. 117–119; February 17, 1961.) An automatic system forms a stored image of the signal after several occurrences. The system alters the stored image as the shape of the signal varies and forms an optimum filter.

621.376.23:621.391.822 2000
Likelihood Detection of Small Signals in Stationary Noise—P. Rudnick. (*J. Appl. Phys.*, vol. 32, pp. 140–143; February, 1961.) An approximation for the detection probability ratio is derived, applicable to any sufficiently long observation period.

621.391.812.624.029.63 2001
Variation in Received Signal Power with Narrow-Beam Antennas Rotated Horizontally in U.H.F. Beyond-the-Horizon Propagation—M. Hirai, R. Inoue, and Y. Kido. (*J. Radio Res. Labs., Japan*, vol. 7, pp. 487–507; September, 1960.) The received signal power depends on the mode of propagation, the geometry of the path and the speed of antenna rotation in addition to the antenna directivities. Assuming tropospheric scatter propagation, the antenna patterns are derived for different distributions of dielectric-constant irregularities and compared with experimental data.

621.396.62:523.164 2002
A 75-cm Receiver for Radio Astronomy and Some Observational Results—Seeger, Stumpers, and van Hurck. (See 1816.)

621.396.62:523.53 2003
Noise Suppression in Pulse Receivers—E. C. McLauchlan. (*Aust. J. Phys.*, vol. 13, pp. 750–752; December, 1960.) Modifications to a receiver system used for measuring meteor rates by radar methods are described. The gain of the video stage is a function of the steady background noise but is unaffected by the signal pulses. The reliability of echo rates during periods of high noise is increased.

STATIONS AND COMMUNICATION SYSTEMS

621.376.56:621.397 2004
Some Techniques of Pulse Code Modulation—W. Neu. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 978–987; October 8, 1960. In English.) Various types of code and methods of code conversion are discussed, and a 54-level tube-type and an 81-level transistor-type coder for television are described.

621.391:621.376.56 2005
Design and Performance of Hyperbolic Binary Encoders—C. P. Villars. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 987–990; October 8, 1960. In French.)

621.396.4:523.3 2006
Band-Pass Measurements of a Lunar Reflection Circuit—R. P. Ingalls, L. E. Bird, and J. W. B. Day. (Proc. IRE, vol. 49, pp. 631–632; March, 1961.) The correlation between signals at frequencies separated by up to 10 kc has been measured. In speech transmision tests SSB modulation was superior to FM.

621.396.65 2007
Intermediate-Frequency Section of a F.M. Radio-Link Installation with Small Number of Channels—A. Schellenberg. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 971–977; October 8, 1960.) Design procedure and theoretical and measured characteristics are given for a 42-Mc IF stage in 7-channel R/T equipment.

621.396.72–519 2008
Remote Control Equipment for Unattended Telecommunication Stations—E. Baranowski. (*Telefunken Ztg.*, vol. 33, pp. 109–119; June, 1960. English summary, p. 157.) The equipment described comprises rack-mounted units for remote supervision and control of repeater and relay stations. The transmission of "reports" and "commands" is carried out by means of pulse trains which actuate stepping selector switches.

621.396.945 2009
Subsurface Communication for Survival—R. N. Ghose. (*Electronics*, vol. 34, pp. 43–45; February 3, 1961.) Theory of a system using underground transmitters and antennas is given.

SUBSIDIARY APPARATUS

621.311.62:537.54 2010
A 30-Kilowatt, 500-Microsecond Vacuum-Tube Pulser—R. A. Kawcyn. (*Rev. Sci. Instr.*, vol. 32, pp. 56–57; January, 1961.) A full description is given of a circuit designed for operation of gas-discharge tubes in plasma research.

621.311.69:621.383.5 2011
Distribution of Losses and the Efficiency of Different Processes in Photoelectric Solar Energy Converters—V. K. Subashiev. (*Fiz. Tverdogo Tela*, vol. 2, pp. 198–204; February, 1960.) An attempt at a quantitative analysis of essential processes is made.

621.352:541.135.6 2012
Theory of Electrochemical Diodes—I. Oshida. (*J. Phys. Soc. Japan*, vol. 15, pp. 2288–2294; December, 1960.) A theoretical analysis is given of the behavior of an electrochemical diode, based on the equation of diffusion of ions. The nonohmic characteristic, the shunting effect observed with a rapidly changing voltage, and the rectifying action are deduced.

TELEVISION AND PHOTOTELEGRAPHY

621.397.132(4):389.6 2013
Standardization of European Colour Television—W. Gerber. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 994–999; October 8, 1960.) The development of existing monochrome standards is reviewed. The discussion deals mainly with the use of the 625-line standards for color television transmission by the NTSC method or its variants, and with related problems of program exchange, transmitter planning and receiver design.

621.397.2 2014
Storage and Frequency-Band Compression in Television—F. Schröter. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 999–1004; October 8, 1960.) The possibilities of reducing television bandwidth by using storage-type picture tubes and taking advantage of the persistence of vision are discussed.

621.397.23:621.396.65 2015
Transmission of Slow Television Pictures over Telephone or Radiotelephone Links—A. Cazalas and B. Picot. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3140–3141; May 9, 1960.) An outline is given of a narrow-band system using an isoscope camera tube developed by Barthélemy (445 of 1946), and a receiver having a display tube with a screen which turns violet-purple color under electron bombardment.

621.397.331.22 2016
A Plug-Type Image-Orthicon Target—S. A. Ochs. (*RCA Rev.*, vol. 21, pp. 558–569; December, 1960.) A new type of target consisting of an array of metal plugs embedded in Al oxide insulating film has been investigated. It has high resolution at low light levels and may be of use as a storage plate.

621.397.61–519 2017
San Salvatore—the First Remotely Controlled Television Relay Station in Switzerland—E. Schwarz. (*Tech. Mitt. PTT*, vol. 38, pp. 201–205; June 1, 1960. In German and Italian.) The remote control of the standard-type video and sound transmitters used is effected by means of pulse signals transmitted via telephone lines.

621.397.611:621.317(083.74) 2018
I.R.E. Standards on Video Techniques: Measurement of Resolution of Camera Systems, 1961—(Proc. IRE, vol. 49, pp. 599–602; March, 1961.) Standard 60 IRE 23.S2.

TRANSMISSION

621.396.61 2019
A Novel Type of High-Power Pulse Transmitter—K. Landecker and K. S. Imrie. (*Aust.*

J. Phys., vol. 13, pp. 638–654; December, 1960.) A symmetrical array of capacitors, charged and discharged as in the Marx impulse generator, is used to generate radio waves. The structure forms the tank circuit and the radiating magnetic dipole, and is capable of producing peak powers of the order of 10^4 mw.

621.396.61:621.395 2020
Transmission Characteristics of Anode-Modulated Telephony Transmitters with Highly Selective Aerials—M. Dick. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 963–971; October 8, 1960.) Distortion, phase modulation and other problems arising from the use of antennas of less than optimum length for long-wave transmitters are investigated theoretically and methods of minimizing the adverse effects are given. Measurements to check the theoretical results were made on a 200-kc, 10-kw transmitter feeding an antenna whose electrical length is about 13 per cent of $\lambda/4$.

TUBES AND THERMIONICS

621.382+537.311.33]:061.3 2021
International Convention on Transistors and Associated Semiconductor Devices—(*Proc. IEE*, vol. 106, pt. B, suppl. nos. 15–18, pp. 265–570, 571–842, 843–1182, and 1183–1398; 1959.) The text is given of the papers presented and the session discussions at the IEE Convention held in London, England, May 27, 1959.

621.382.2/.3 2022
Effects of Electrons and Holes on the Transition-Layer Characteristics of Linearly Graded *p-n* Junctions—C. T. Sah. (PROC. IRE, vol. 49, pp. 603–618; March, 1961.) The dc theory of *p-n* junctions has been extended, taking into account the mobile carriers or electrons and holes in the transition region under forward-bias conditions both the transition-layer width and carrier capacitance increase exponentially with voltage.

621.382.22:621.318.57 2023
A 100-dB Microwave Semiconductor Switch—D. W. Feldman and B. R. McAvoy. (*Rev. Sci. Instr.*, vol. 32, pp. 74–76; January, 1961.) "A dual-diode microwave switch providing in excess of 100-dB switched attenuation with low insertion loss is described. Switching time of the device, limited by the diodes, is 3×10^{-7} sec. Application of the switch in a 9-Gc/s superheterodyne magnetic resonance spectrometer as a mixer crystal protector and as a microwave signal blanker is described."

621.382.23 2024
The Current Ratio I_{max}/I_{min} of Tunnel Diodes—M. Michelitsch. (*Naturwiss.*, vol. 47, p. 274; June, 1960.) The ratio is shown to be strongly dependent on the duration of the alloying time.

621.382.23 2025
Current/Voltage Characteristics of Alloyed and Diffused *p-n* Junction Diodes in InSb—H. J. Stocker. (*J. Appl. Phys.*, vol. 32, p. 322; February, 1961.) Measurements on sample diodes at liquid-nitrogen temperatures are described. The rectification ratios are two orders of magnitude higher than previously reported in the literature.

621.382.23:621.372.44 2026
High-Frequency Varactor Diodes—C. W. Mueller and R. D. Gold. (*RCA Rev.*, vol. 21, pp. 547–557; December, 1960.) Fabrication, impurity distribution, and the measurement of electrical characteristics at 2 Gc are described. These diodes have been used as phase-locked oscillators up to 17 Gc (pump frequency 34 Gc) and have also been used in microwave strip-line amplifiers.

621.382.233:621.318.57 2027
Theoretical Current Multiplication of a Cylindrical Hook Collector—D. P. Kennedy. (*IBM J. Res. & Dev.*, vol. 5, pp. 25–32; January, 1961.) A theoretical analysis of the "hook collector" which is an integral part of most four-layer, *p-n-p-n*, semiconductor switches. Design equations are presented in graphical form.

621.382.3 2028
Some Transconductance Measurements on Transistors—C. Milone. (*Note Recensioni Notiz.*, vol. 9, pp. 541–553; May/June, 1960.) Investigations are discussed of commercial-type transistors in earthed-emitter configuration under various operating conditions.

621.382.3 2029
Transistor Upper Noise Corner Frequency—H. F. Cooke. (PROC. IRE, vol. 49, p. 648; March, 1961.) Measured values of the upper noise corner frequency of four types of transistor have been compared with values calculated from a) the classical formula [757 of 1959 (Shea)], b) a more exact form of the expression derived by Nielsen (3337 of 1957) and c) the expression used in b), but substituting the transition frequency f_T in place of f_α. Over a range of cutoff frequencies from 40 to 600 Mc very good agreement was obtained between the measured values and those calculated by method b).

621.382.3–71 2030
Heat Dissipation of Transistors—W. Hilberg. (*Telefunken Ztg.*, vol. 32, pp. 200–207; September, 1959. English summary, pp. 211–212.) From a consideration of the heat conduction and dissipation processes in a transistor an equivalent circuit for the heat dissipation under static conditions is derived. Calculations regarding the thermal characteristics under dynamic conditions are based on this circuit and several simplifying assumptions. Methods are described for determining the barrier-layer temperature from measurements of transistor operating characteristics.

621.382.333 2031
A *p-n-p* High-Frequency Silicon Transistor—W. A. Little. (*J. Electrochem. Soc.*, vol. 107, pp. 789–791; September, 1960.) The construction and electrical characteristics of a double-diffused transistor are described.

621.382.333:621.318.57 2032
Properties and Applications of Junction Transistors as Switches—G. Meyer-Brötz. (*Telefunken Ztg.*, vol. 33, pp. 85–98; June, 1960. English Summary, p. 156.) The basic static and dynamic characteristics of junction transistors are examined for suitability in switching applications. The design of electronic switches with minimum residual voltage and current, and of transistor modulators for amplifier control is also considered. 44 references.

621.382.333.002.2 2033
Conditions for Obtaining Germanium Transistors by Double Diffusion—R. Deschamps. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3137–3139; May 9, 1960.) A theoretical examination of conditions necessary for the production of an *n-p-n*-type transistor.

621.382.333.002.2 2034
Conditions for Applying Double Diffusion to Obtain Germanium Transistors—R. Deschamps. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3290–3292; May 16, 1960.) Experimental results are described which confirm the theoretical conditions laid down in a previous paper (2033 above).

621.383.292.001.4 2035
Investigations of the Local Characteristics of Photomultipliers—P. Cachon. (*Ann. Telecommun.*, vol. 15, pp. 220–251; September/October, 1960.) A detailed report is given of work noted earlier (736 of February).

621.383.5 2036
Energy Diagram of a Real Silicon Photocell—V. K. Subashiev and É. M. Pedyash. (*Fiz. Tverdogo Tela*, vol. 2, pp. 213–220; February, 1960.) A description of a method for constructing the energy diagram of a photocell with its equlibrium carrier concentration is given. Two examples relating to photocells obtained by diffusion of Sb into *p*-type Si show the necessity for considering the field and potential drop in the diffusion layers when studying the operation of a cell.

621.383.5 2037
The Theory of Photocells with a *p-n* Junction—B. Ya. Moĭzhes. (*Fiz. Tverdogo Tela*, vol. 2, pp. 221–226; February, 1960.) An investigation is made of the effect of the distributed impedance of the current-removal layer on the characteristics of the photocell and of the movement of minority carriers in the diffusion layer taking account of the extended field and the changing mobility.

621.384.64 2038
Statistical Equilibrium of an Electron Space Charge with Cylindrical Symmetry in a Magnetron—J. Coste and L. Dagens. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3009–3011; May 2, 1960.)

621.385.029.6 2039
Systematization and Technical State of Microwave Valves—L. Brück and W. Klein. (*Frequenz*, vol. 14, pp. 198–210; June, 1960.) Transit-time tubes and disk-seal triodes are reviewed with details of several commercial types.

621.385.032.21 2040
Potential Distribution above a Serrated Cathode—E. Weber. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1011–1014; October 8, 1960. In English.) The potential distribution is determined by means of the method of conformal mapping.

621.385.032.213 2041
Thermionic Emission Constants and their Interpretation—E. B. Hensley. (*J. Appl. Phys.*, vol. 32, pp. 301–308; February, 1961.) A critical review of the procedures used in the measurement and interpretation of thermionic emission with particular reference to nonmetallic cathodes.

621.385.2:621.391.822:621.372 2042
Nonlinear Thermal Fluctuations in a Diode—Van Kampen. (See 1742.)

621.385.3 2043
Nonlinear Distortion due to Transit Time Effects in Single-Grid Valves—H. Leysieffer. (*Arch. elekt. Übertragung*, vol. 14, pp. 269–282; June, 1960.) An investigation is made of the relation between transit phase angle and distortion dependent on transit time in amplifier triodes for use in SSB radio-link systems. Calculations deal with cubic distortion as only this alone can give rise to interference in the dm-λ range considered. Conditions in the cathode-grid and grid-anode spaces are treated separately. Measurements made for transit phase angles up to about 140° give results in closer agreement with theory for the grid-anode space than for the cathode-grid space.

621.385.6+621.382.23]:621.375.029.6 2044
Amplification—Modern Trends, Techniques and Problems—L. S. Nergaard. (*RCA Rev.*, vol. 21, pp. 485–507; December, 1960.) A review is given of the characteristics of traveling-wave tubes, tunnel diodes, parametric amplifiers and masers.

621.385.624 2045

The Amplification of Multiresonator Klystrons—H. Hagger. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1041–1046; October 8, 1960.) The gain of n-resonator klystrons is calculated using Derfler's theory of electron-beam interaction with a space-periodic structure (3438 of 1955). Results obtained are compared with theoretical and experimental data for various klystrons.

621.385.63:621.375.9:621.372.44 2046

Energy Balance in a Parametric Electron-Beam Amplifier—G. K. Grau. (*Arch. elekt. Übertragung*, pp. 247–255; June, 1960.) General energy relations are derived for the longitudinal parametric electron-beam amplifier. Using the principles adopted by Kogelnik (4245 of 1959), dc and ac energy flows can be separated. The energy relations obtained correspond to the Manley-Rowe relations and are discussed with reference to the analysis of Roe and Boyd (3420 of 1959).

621.385.63:621.375.9:621.372.44 2047

Coupled-Mode Theory of Electron-Beam Parametric Amplification—R. W. Gould and C. C. Johnson. (*J. Appl. Phys.*, vol. 32, pp. 248–258; February, 1961.) The theory is applied to amplification by transverse fields. Beam modes at a series of frequencies in addition to the signal frequency are coupled together. Quadrupole electric pump fields and the noise contribution from synchronous beam modes and higher cyclotron idler modes are discussed. Coupling by axially symmetric electric and magnetic fields, and lens effects on noise in the gun region are considered.

621.385.63:621.375.9:621.372.44 2048

A Cyclotron Wave Amplifier with Magnetic Pumping—P. N. Robson. (PROC. IRE, vol. 49, pp. 645–646; March, 1961.) A transverse twisting magnetic field is used to couple the fast and slow cyclotron waves.

621.385.63:621.391.822 2049

Reduction of Beam Noisiness by means of a Potential Minimum away from the Cathode—W. M. Mueller. (PROC. IRE, vol. 49, pp. 642–643; March, 1961.) A sudden discontinuous decrease in the noise figure of a traveling-wave tube was observed as the potential of the profile-shaping electrode was increased. This effect is discussed in relation to a simultaneous drop in the collector current. Explanations for the discontinuities are suggested. See also 1727 of 1959 (Currie and Forster).

621.385.632 2050

Bi-signal Amplification by a Forward-Wave Crossed-Field Amplifier—R. J. Collier. (PROC. IRE, vol. 49, p. 646; March, 1961.) Simultaneous amplification of two pulsed signals differing in frequency has been observed at X-band frequencies using a forward-wave crossed-field amplifier with emitting sole whose gain characteristics have been described earlier (*ibid.*, vol. 49, p. 372; January, 1961.). Results indicate that the system operates as a saturated amplifier rather than a locked oscillator.

621.385.69 2051

A Proposed Doppler-Helitron Oscillator—B. W. Hakki. (PROC. IRE, vol. 49, p. 626; March, 1961.) A method is proposed for magnifying the cyclotron frequency of a helical electron beam by 20–100 times through a Doppler shift.

621.385.832 2052

The Cathode Loading Limit in Circular-Beam Electron Devices—H. Moss. (*J. Brit. IRE*, vol. 21, pp. 35–39; January, 1961.) The analyses of Haine (2993 of 1957) and Schwartz (4054 of 1957) are extended and combined to develop a semi-universal curve which shows that low cathode loadings (0·1 a/cm²) are sufficient to cause severe beam-focus degradation, due to space-charge effects, for spot sizes common in normal CRT's.

621.385.832 2053

Selective Erasure and Nonstorage Writing in Direct-View Half-Tone Storage Tubes—N. H. Lehrer. (PROC. IRE, vol. 49, pp. 567–573; March, 1961.) A new type of storage tube that can erase selectively and display simultaneously stored and nonstored information has been developed. It incorporates a dual-effect target using secondary emission for writing and bombardment-induced conductivity for erasure.

621.385.832:621.396.963.3 2054

Practical Tubes for Bright Radar Displays—F.S. Veith. (*Bull. schweiz. elektrotech. Ver.*, vol. 51, pp. 1023–1030; October 8, 1960. In English.) Display and scan-conversion storage tubes are described.

621.387:621.318.57 2055

The Use of a Hot-Cathode Gas Diode for making a Short Sharp Interruption of Microwave Transmission—M. Laporte. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3145–3146; May 9, 1960.) The relative performances of hot- and cold-cathode TR switches are considered and a helium-filled hot-cathode type is proposed having a permanently applied anode voltage which is slightly less than the ionizing potential of the gas.

621.387:621.318.57 2056

Study and Experimental Investigation of a Hot-Cathode Gas Diode for the Construction of a Microwave Switch—J. Godart. (*Compt. rend. Acad. Sci., Paris*, vol. 250, pp. 3299–3301; May 16, 1960.) Following the proposal of Laporte (2057 above), experimental results have been obtained using a hot-cathode TR switch. These show a more rapid response time and a greater sensitivity than can be obtained using a cold-cathode type of cell.

621.387:621.362 2057

A New Thermionic Generator—Gabor. (See 1969.)

621.387:621.362 2058

Low-Frequency Oscillations in a Filamentary-Cathode Cesium Diode Converter—Luke and Jamerson. (See 1970.)

621.387:621.374.32 2059

A Gas-Discharge Indicator Tube for Transistorized Decade Counting Circuits—T. P. J. Botden. (*Philips Tech. Rev.*, vol. 21, pp. 267–275; August 4, 1960.) A description of an indicator tube which responds to the small signals delivered by transistor circuits is given.

MISCELLANEOUS

061.3:[537.311.33:621.382 2060

International Semiconductor Symposium—(*Wireless World*, vol. 67, p. 191; April, 1961.) A brief report is given of the symposium organized by the S.F.E.R. and held in Paris, France, February 20–25, 1961.

061.4:621.3 2061

Physical Society Exhibition [1961]—(*Wireless World*, vol. 67, pp. 106–115; March, 1961.) Brief descriptions are given of selected exhibits.

001.891:621.396 2062

Radio Research 1959: The Report of the Radio Research Board and the Report of the Director of Radio Research [Book Review]—Her Majesty's Stationery Office, London, England, 34 pp., 1960, 3s. (*Nature*, vol. 189, pp. 539–540; February 18, 1961.)

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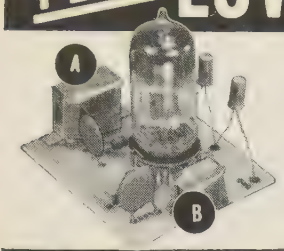
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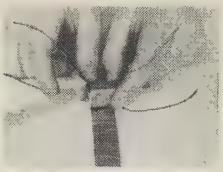
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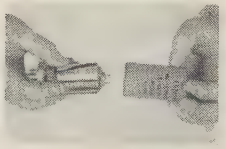
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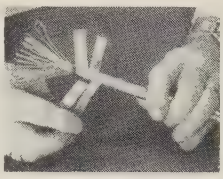
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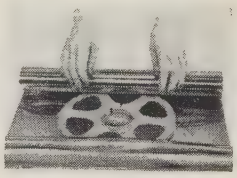

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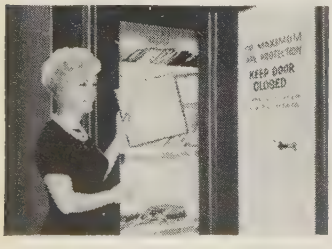
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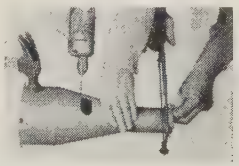


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Boston—April 11

"System Engineering the ARSR-1 FAA Radar for Joint Use with the U. S. Air Force and Army," Capt. E. Warner, CCDD, ARDC, USAF; C. Bracket, Rescon Electronics.

Florida West Coast—May 10

"Microelectronics," N. J. Doctor' Diamond Ordnance Fuze Labs., Washington, D.C.

Florida West Coast—May 3

"Microelectronics," A. Evans, Texas Instruments, Inc., Dallas, Tex.

Florida West Coast—April 26

"Microelectronics," V. DeFillipo, RCA Semiconductor Div., Somerville, N.J.

Florida West Coast—April 19

"Microelectronics," D. S. Dunovan, Sperry (Semiconductor Division), Norwalk, Conn.

Florida West Coast—April 12

"Microelectronics," Dr. C. Feldman, Melpar, Inc., Falls Church, Va.

Antennas and Propagation

Boston—April 6

"Pattern Deterioration in Large Antennas," T. J. Skinner. AFCRC.
"Large Ground-Based Rigid Radomes," A. Cohen, Lincoln Labs.

Los Angeles—February 28

"Recent Advances in Theory and Development of Antenna Arrays," N. Yark, Hughes Aircraft Co., Fullerton, Calif., and L. Kurtz, Rantec Corp., Calabasas, Calif.

San Francisco—April 12

"Study and Design of Unfurlable Antennas," Dr. P. D. Kennedy, Lockheed Missiles and Space Division.

Washington, D. C.—April 18

"The 1000 Foot Antenna for Department of Defense Ionospheric Research Facility," B. Hagaman, Developmental Engineering Corp., Leesburg, Va.

Antennas and Propagation Microwave Theory and Techniques

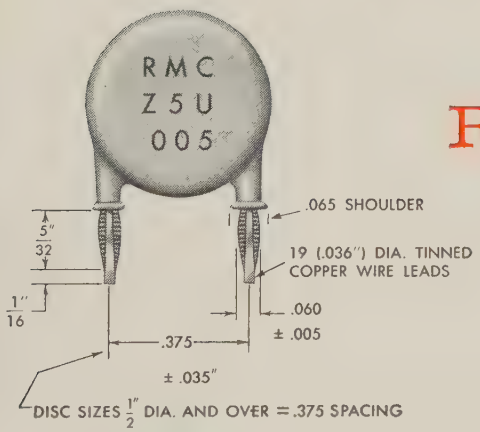
Orange Belt—April 20

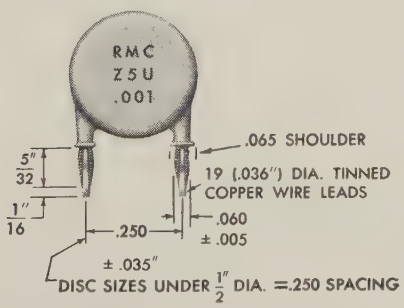
"A New Radar System Utilizing Laser Techniques," Dr. G. Smith, Hughes Research Labs.

(Continued on page 68A)

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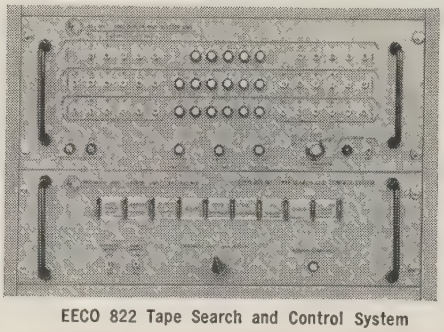
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A DIVISION OF P. R. MALLORY & CO., INC.
GENERAL OFFICE: 4242 W. Bryn Mawr Ave., Chicago 46, Ill.
Two RMC Plants Devoted Exclusively to Ceramic Capacitors
FACTORIES AT CHICAGO, ILL. AND ATTICA, IND.

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HOURS/MINUTES/SECONDS/HOURS/MINUTES/SECONDS/ HOURS/MINUTES/SECONDS

TIME TRICK

FIND A NEEDLE IN A 13-FOOT HAYSTACK IN 1 SECOND

WITH EECO's TIME-CODED MAGNETIC TAPE SEARCH AND CONTROL SYSTEMS



EECO 822 Tape Search and Control System
Referenced for Atlantic Missile Code Ranges

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EECO 822	9,500	EECO 842	4,750	17-Bit, 24-hour, Binary Code as produced by TCG* EECO 802 (Eglin AFB and Atlantic Missile Range codes)
EECO 823	10,200	EECO 843	5,100	20-Bit, 24-hour, BCD code as produced by TCG* EECO 803
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*Time Code Generator

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Professional Group Meetings

(Continued from page 66A)

Audio
Microwave Theory and Techniques

Baltimore—April 11

"Related Experiments in Audio Waves and Microwaves," Dr. W. E. Kock, Bendix Research Div., Detroit, Mich

Automatic Control

Baltimore—March 9

"The Mathematics of Modern Control Theory," Dr. N. H. Choksy, Johns Hopkins University, Silver Spring, Md.

Dallas-Fort Worth—May 16

"Twin Gyro Space Vehicle Controller," D. F. Sellers, Chance Vought Electronics, Arlington, Tex.
Plant Tour.

Dallas-Fort Worth—April 25

"Digital Actuator," R. H. Meyers, Chance Vought Electronics Div., Arlington, Tex.

Los Angeles—April 11

"Application of Inertial Guidance to Space Mission," Dr. G. R. Pitman, Jr., Hughes Aircraft Co., Culver City.

Philadelphia—March 15

"Digital Computer Control-Analysis, Hardware and Applications," Dr. K. W. Goff and D. R. Whitten, Leeds & Northrup Co., North Wales, Pa., and G. Bekampis, Philco Corp., Willow Grove, Pa.

Philadelphia—February 23

"Analog Computation Technique in On-Line Process Control," E. B. Dahlin, Minneapolis-Honeywell Regulator Co., Philadelphia, Pa.

Schenectady—January 24

"Trial and Error Methods of Design of Feedback Control Systems," Dr. P. DeRusso, Rennselaer Polytech. Inst., Troy, N. Y.

"Analytical Methods for the Design of Feedback Control Systems," Dr C. Merriam III, Research Lab., General Electric Co.

Bio-Medical Electronics

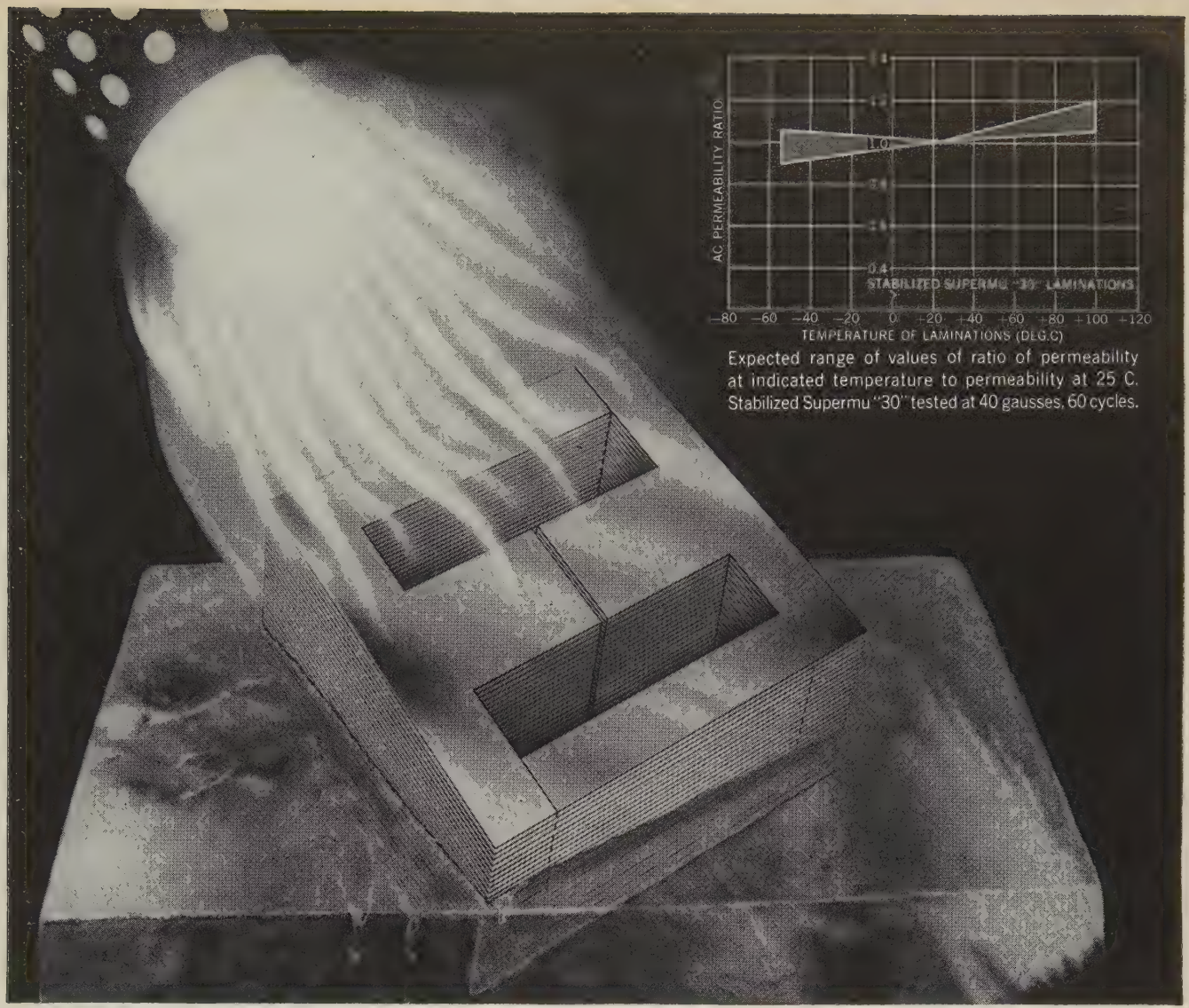
Boston—March 28

"The World of the Electron Microscope," Dr. H. Fernandez-Moran, Massachusetts General Hospital, Boston.

Cleveland—April 26

"Measurement of the Total Arterial Bloodflow in Active Animals," F. Olmsted, Cleveland Clinic Foundation, Cleveland.

(Continued on page 72A)



Expected range of values of ratio of permeability at indicated temperature to permeability at 25 C. Stabilized Supermu "30" tested at 40 gausses, 60 cycles.

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THERMALLY STABLE TRANSFORMER LAMINATIONS

If you're designing a transformer or reactor that must maintain constant inductance under the blazing desert sun or in the sub-zero cold of the Arctic or outer space, you need our thermally stable Supermu "30" laminations. They're the only temperature-stabilized laminations available anywhere.

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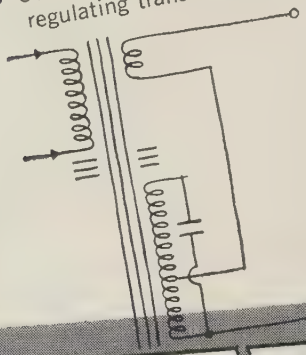
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853 Production Place, Newport Beach, California
transformer laminations • motor laminations • tape-wound cores
powdered molybdenum permalloy cores • electromagnetic shields

SOLA ...for progress

WEDNESDAY, JULY 13

1938

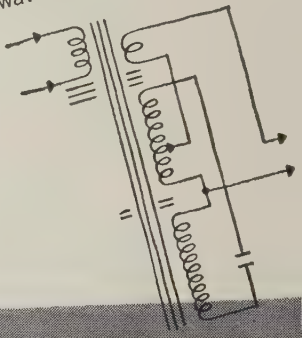
• CVN — the first practical regulating transformer



FRIDAY, SEPTEMBER 3

1948

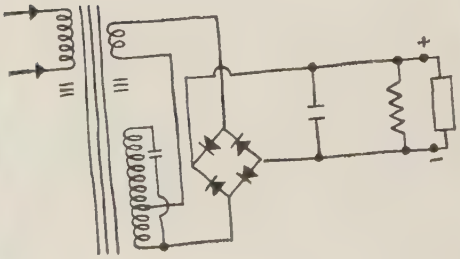
• CVS — the first integrally packaged sine wave regulating transformer



THURSDAY, AUGUST 19

1954

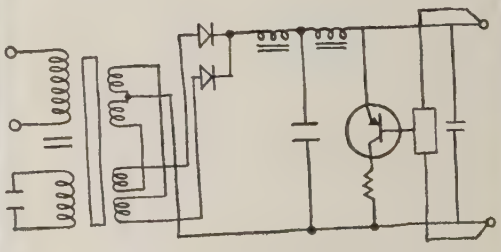
• CVDC — the first static-magnetic dc power supply



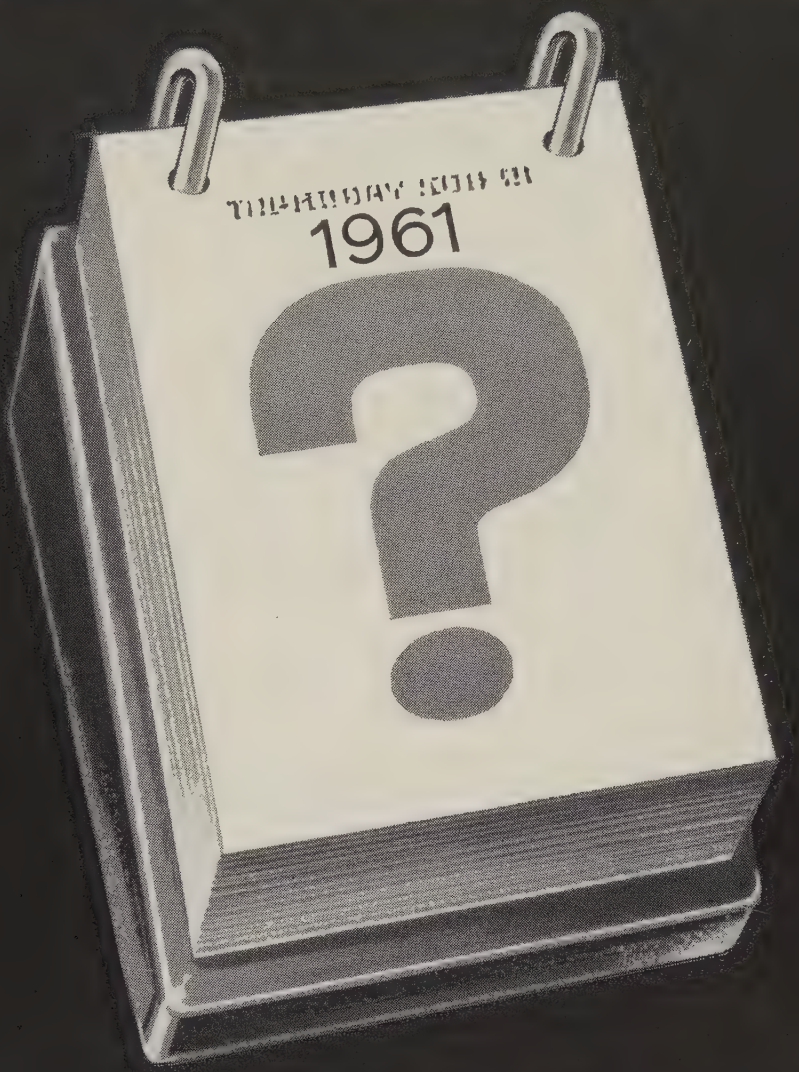
TUESDAY, FEBRUARY 7

1961

• CVQ — the first ultra-reliable transistorized dc power supply



in "engineered" voltage regulation



The most significant thing about past performance is the promise it holds for the future. Each day, our engineering moves forward toward new milestones. We will welcome your problems in ac or dc power regulation. For immediate attention, write or phone Mr. A. Steichen, Product Manager, Electronics, Sola Electric Company, Elk Grove Village, Illinois.

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B P C

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1717 Busse Road
Elk Grove Village, Ill.
HEmpstead 9-2800
IN CANADA, Sola-Basic Products Ltd., 377 Evans Ave., Toronto 18, Ont.

Professional Group Meetings

(Continued from page 68A)

"Measurement of the Microcirculation," E. H. Bloch, Western Reserve University Medical School, Cleveland.

Laboratory tour of the Medical School laboratories, with demonstrations of several examples of microcinematography and display of the microcirculation and living cells, including spot scanning techniques.

Omaha-Lincoln—April 24

"Fifth Annual Medical Electronics Symposium"

D. Josephson, Omaha Central High School, Westinghouse Science Talent Search Finalist, demonstration of Polaroid Ampli-Photometer.

J. Heimforth, Philips Electronics, Chicago, Commentary on two Philips Movies on Electron Microscopy.

J. C Mead, Philips Electronics, Chicago, Demonstration of Philips Electron Microscope.

D. Rhea, University of Nebraska, Demonstration of Microtome and Slide Preparation.

Dr. J. Barmore, University of Nebraska, Demonstration of External Heart Resuscitation by Breastbone Pressure Method.

Dr. D. J. Mahler, Omaha VA Hospital, Demonstration of Spinco Electrophoresis Fractionator for Urinalysis, etc.

G. Thrane, Omaha Benson High School, Demonstration of Powder Version of Milliken Oil Drop Experiment for Measuring Charge on Electron.

San Francisco—April 19

"The Biological Effects of Air Ions," P. Andriese and S. Kotaka, Dept. of Bacteriology, University of California, Berkeley.

San Francisco—March 22

"Information Handling Process in Brain Systems in Computer Analysis of Brain Wave Data," Dr. W. R. Adey, University of California Medical Center, Los Angeles.

Broadcasting

Florida West Coast—March 22

"Electronic Countermeasures and Associated Techniques Used in Air Defense Commands Dew Line Installation," Maj. S. W. Miller, USAF, MacDill AFB.

Circuit Theory

Chicago—April 14

"Statistical Methods in Circuit Theory," H. P. Messinger, ITT Kellogg, Chicago, Ill.

(Continued on page 90A)

Another New High Order of Reliability!

El-Menco *MYLAR-PAPER DIPPED CAPACITORS TYPE MPD



ASSURE A LOW FAILURE RATE OF

Only 1 Failure in ~~7,168,000~~ 14,336,000 Unit-Hours for 0.1 MFD Capacitors★

Setting A New High Standard Of Performance!

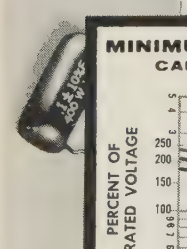
★ Life tests have proved that El-Menco Mylar-Paper Dipped Capacitors — tested at 105°C with rated voltage applied — have yielded a failure rate of only 1 per 1,433,600 unit-hours for 1.0-MFD. Since the number of unit-hours of these capacitors is inversely proportional to the capacitance, 0.1 MFD El-Menco Mylar-Paper Dipped Capacitors will yield ONLY 1 FAILURE IN 14,336,000 UNIT-HOURS.

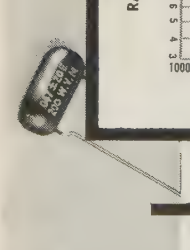
CAPACITANCE AND VOLTAGE CHART

• Five case sizes in working voltages and ranges:

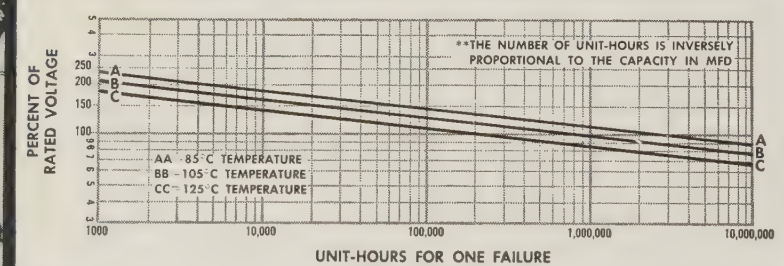
200 WVDC —	.018 to .5 MFD
400 WVDC —	.0082 to .33 MFD
600 WVDC —	.0018 to .25 MFD
1000 WVDC —	.001 to .1 MFD
1600 WVDC —	.001 to .05 MFD







MINIMUM LIFE EXPECTANCY FOR **1.0 MFD *MYLAR-PAPER DIPPED CAPACITORS AS A FUNCTION OF VOLTAGE & TEMPERATURE



Write for Technical Brochure

*Registered Trade Mark of DuPont Co.

THE ELECTRO MOTIVE MFG. CO., INC.

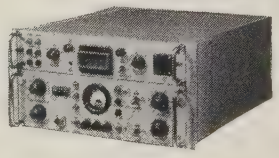
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Exclusive Supplier To Jobbers and Distributors in the U.S. and Canada
WEST COAST MANUFACTURERS CONTACT:
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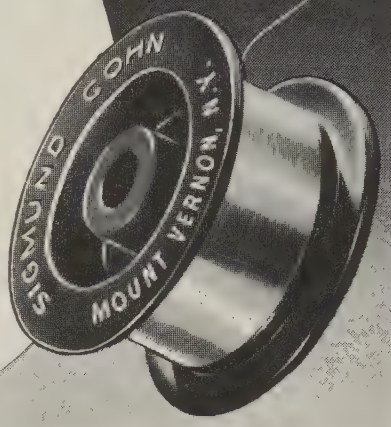
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SM 14-7M	0–14	0–7	SM 14-7MX
SM 36-5M	0–36	0–5	SM 36-15MX
SM 75-2M	0–75	0–2	SM 75-2MX
SM 160-1M	0–160	0–1	SM 160-1MX
SM 325-0.5M	0–325	0–0.5	SM 325-0.5MX

5¼" PANEL HEIGHT

SM 14-15M	0–14	0–15	SM 14-15MX
SM 36-10M	0–36	0–10	SM 36-10MX
SM 75-5M	0–75	0–5	SM 75-5MX
SM 160-2M	0–160	0–2	SM 160-2MX
SM 325-1M	0–325	0–1	SM 325-1MX

8¾" PANEL HEIGHT

SM 14-30M	0–14	0–30	SM 14-30MX
SM 36-15M	0–36	0–15	SM 36-5MX
SM 75-8M	0–75	0–8	SM 75-8MX
SM 160-4M	0–160	0–4	SM 160-4MX
SM 325-2M	0–325	0–2	SM 325-2MX

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DATA RECORDING & DISPLAY				•		•
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COMPUTERS (Digital) Applications	•	•	•	•	•	•
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SEMICONDUCTORS-Circuitry, Devices	•		•	•	•	
PHYSICS (Military & Commercial Applications)						
Space	•	•	•		•	
Accoustics	•	•	•	•	•	•
Electron Optics	•	•	•		•	
Electromagnetics	•	•	•	•	•	•
TELEVISION (Broadcast & Industrial)						
Receivers	•	•	•	•	•	•
Transmitters (AM, FM & TV)			•	•	•	•
HF Video & Audio Techniques	•		•	•	•	
TUBES — Cathode Ray	•		•		•	
AUTOMATED MACHINE CONTROLS		•	•		•	

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(Continued on page 76A)



THANKS FOR SHARING THE LOAD, DR. MAXWELL!

Your equations together with Newton's Laws serve as a basis for explaining classical electromagnetic phenomena. Most important among the outgrowths of your theory are radio and its allied invention, radar. At AC, we are using techniques for the generation and propagation of electromagnetic waves to increase the total capabilities of the B-52 weapons system.

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SPACE TECHNOLOGY LABORATORIES, INC.

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P. O. Box 95005 I, Los Angeles 45, California

Positions Open

(Continued from page 74A)

junior engineering students. Candidate must have B.S. degree and be willing to take graduate work at nearby University. (2) Assistant, associate or full Professor: to teach electronics and senior E.E. electives. Candidate should possess a graduate degree (MS. or Ph.D.) specializing in electronics and/or communications. Encouragement given to private research and consultation. Rank and salary commensurate with academic attainment and experience. Apply: L. M. Gonsalves, Chairman, Dept. of E.E., New Bedford Institute of Technology, New Bedford, Mass.

ENGINEERING—PHYSICIST

Teaching and Research Engineer-Physicist-Mathematician needed in the following areas: Dynamics, Statics (including theories on elasticity and viscoelasticity), Heat and thermodynamics, electricity, physical optics, and "Modern Physics." This is a staff and faculty appointment with full participation in our graduate school program. Write for information, academic catalog, and application form to: The Director of Personnel, The Institute of Paper Chemistry, Appleton, Wisconsin.

ELECTRONICS INSTRUCTOR

Junior College: to teach general electronics theory and math., pulse circuits, measurements, transistors. State experience in the fields of TV, radar, computers, magnetic amplifiers, microwaves. Send résumé and references to College Supervisor, Certified Selection. Personnel Div., Los Angeles City Board of Education, 450 North Grand Ave., Los Angeles 12, Calif.

PART TIME EMPLOYMENT

Part time job for semi-retired salesman experienced in electrical-electronic-mechanical field. Newly established company. Commission basis. Telephone SA 2-2335 or write Box 2051.

ENGINEER—MATHEMATICIAN

We should like to add a Statistical Mathematician to our staff, who would be concerned with problems in the information processing area—more specifically, projects utilizing statistical decision theory, perception recognition and factor analysis. An example of some current research in this area is Pattern Recognition Studies: decision criteria, tests, statistical analysis, and rating factors applicable to pattern recognition problems are being investigated. Mathematical models including the use of the analysis of stochastic processes will be used to develop criteria and system parameters within the various areas of recognition research, information retrieval and artificial intelligence. Send inquiries to Dr. L. S. Sheingold, Director, Applied Research Lab., Sylvania Electronic Systems, 100 First Ave., Waltham 54, Mass.

DELAY LINES

Electrical Engineer with design experience involving components for pulse circuitry with emphasis on lumped and distributed delay lines. Background in filters, R.F. coils, and pulse transformers also desirable. This position with progressive and expanding eastern components manufacturer, offers excellent opportunity for eventual advancement to position of Chief Engineer. Send complete résumé and salary requirements with first letter to Box 2052.

ASSISTANT PROFESSOR OF ELECTRICAL ENGINEERING

Ph.D. required with special interests in circuits, controls or electromagnetic theory to teach and do

(Continued on page 78A)

New Positions at

SYLVANIA

RESEARCH & DEVELOPMENT LABORATORIES

on the San Francisco Peninsula

The Reconnaisance Systems Laboratory and Electronics Defense Laboratories are expanding their R&D facilities and advancing the state of the art—as well as America's defense capabilities—at Sylvania Mountain View Operations. Here, in the heart of the San Francisco Peninsula, numerous new electronics research and development programs are under way. Challenging positions for electronic engineers exist at all levels. Positions include:

Origination of Advanced Systems and Equipment Concepts

Design of Unique Electronic Circuits

Development of Experimental Electronic Equipment

in the following areas:

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SYSTEMS ANALYSIS
OPERATIONS RESEARCH
PROPAGATION STUDIES
SIGNAL ANALYSIS
RECEIVER SYSTEMS
TRANSMITTERS
D. F. SYSTEMS
MECHANICAL DESIGN

B. S. or M. S. degree and U. S. citizenship required; Ph. D. required for some positions. For further information, please contact Mr. R. R. Keeffe at Box 188, Mountain View, Calif.

All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

SYLVANIA ELECTRONIC SYSTEMS
Government Systems Management
for GENERAL TELEPHONE & ELECTRONICS

GENERAL SYSTEM

6922

ACF ELECTRONICS



You can bring new meaning to your career in engineering by investigating opportunities in state-of-the-art developments at ACF. Experienced engineers at all levels are cordially invited to inquire about challenging positions in the following fields:

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SIMULATOR ENGINEERING
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HF, RF COMMUNICATIONS
MICROWAVE COMPONENTS & SYSTEMS
OPTICS & INFRARED
AIRBORNE RADAR SYSTEMS
FIELD ENGINEERING

These openings involve assignments at our laboratories located in SUBURBAN WASHINGTON, D. C. and the New York metropolitan area at Paramus, New Jersey. Pleasant residential neighborhoods provide readily available housing. Advanced study under tuition refund may be conducted at nearby universities. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

Send resume to
A. C. SUGALSKI
Manager,
Professional Employment
at our Riverdale Facility
Dept. 2

ACF ELECTRONICS
DIVISION

ACF INDUSTRIES

RIVERDALE, MARYLAND • HYATTSVILLE, MARYLAND • PARAMUS, NEW JERSEY

Positions Open

(Continued from page 76A)

research. Foreign applications welcome. Apply to Chairman of E.E. Dept., Villanova University, Villanova, Pa.

PROFESSORS

The Air Force Institute of Technology, Wright-Patterson AFB, Ohio has a vacancy in the Dept. of Mathematics. Most of the work is at advanced undergraduate and graduate level. One quarter out of four free of teaching duties for research or other academic pursuits, plus vacation. Working conditions comparable to those in leading universities. Employment will be effected in accordance with Civil Service regulations. Rank and salary will depend on qualifications of applicant and may be anywhere between Assist. Professor, GS-11, $7560.00, and full Professor, GS-14, $12210.00. Applications should be made on Standard Form 57, available at any P.O. or by letter to Head, Dept. of Mathematics, Institute of Technology, Wright-Patterson AFB, Ohio.

ELECTRONIC RESEARCH ENGINEERS

4-20 years experience, M.E.E. or D.E.E. Research positions are open for Senior Electronic Engineers interested in sophisticated programs on multi-dimensional radar resolution, secure communications, space guidance, AICBM radar, superresolution pulse compression and long range sonar. The work includes theoretical and laboratory research relating to communication and radar systems analysis, network synthesis, digital techniques, statistical communication theory, com-

(Continued on page 82A)

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Are you on the way up, or are you bogged down in a job with no future? The firms that perform the important work, that employ the best people, that are growing fastest, use Abbott's Employment Specialists to meet their recruiting needs. Abbott's can give you the inside track on important opportunities in science and engineering.

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ELECTRICAL ENGINEERS: phased array radar, sonar, power supplies, communications, infra-red, data processing.

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Said Svante Arrhenius: *"The change of the logarithm of a chemical reaction rate constant with respect to temperature, is inversely proportional to the square of the absolute temperature."*

The aerospace industry is searching constantly for strong, light-weight, heat-resistant materials. Finely-spun glass fiber, bonded with a plastic binder, is beginning to exhibit superior properties. Until recently the glass fiber has been far more heat-resistant than any binder.

Scientists at Lockheed Missiles and Space Division, however, have developed a compatible binder. This now makes it necessary for the glass-producing industry to evolve a glass to match its superior heat-resistance.

Comparable successes are being achieved in dozens of disciplines in which Lockheed is engaged. As Systems Manager for the DISCOVERER, MIDAS, and other satellites, and the POLARIS FBM, Lockheed probes all areas of aerospace endeavor.

Lockheed Missiles and Space Division is located on the beautiful San Francisco Peninsula, in Sunnyvale and Palo Alto, California. Why not investigate future possibilities at Lockheed? Write Research and Development Staff, Dept. M-30C, 962 West El Camino Real, Sunnyvale, California. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. U.S. citizenship or existing Department of Defense industrial security clearance required.

Lockheed / **MISSILES AND SPACE DIVISION**

Systems Manager for the Navy POLARIS FBM and the Air Force AGENA Satellite in the DISCOVERER and MIDAS Programs

SUNNYVALE, PALO ALTO, VAN NUYS, SANTA CRUZ, SANTA MARIA, CALIFORNIA • CAPE CANAVERAL, FLORIDA • HAWAII

Honeywell Aero... for the best of both

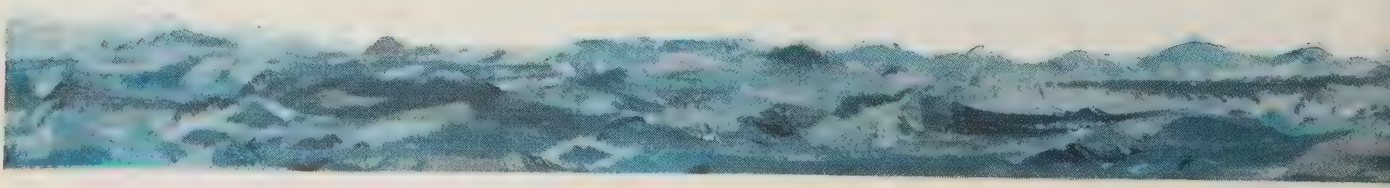


CLIMATE FOR CREATIVITY:

This is an artist's conception of the Air Force space craft Dyna Soar. Honeywell Aero has been selected both as an associate and as a sub-contractor for the critical guidance and flight control subsystems respectively on this delta-winged space craft that will carry one or more astronauts. The Dyna Soar will be sent into space by a Titan booster.

The Dyna Soar project is representative of the many advanced systems which are being evolved and developed into working hardware at Honeywell Aero. It is typical of the type of creative concept that poses a challenge to the engineer or scientist possessing imagination, drive, and talent.

You will find in the Aero division an opportunity to associate with those who understand, appreciate and respond to the creative individual. In the process you will grow in professional stature and have your accomplishments recognized and rewarded.



CLIMATE FOR ENJOYMENT:

Sailing, canoeing, power-boating, water skiing or fishing, you'll find opportunity for all in the Minneapolis area. Within the city limits are three sailboat docks, five canoe docks, and four large lakes for game fishing. A half-hour away lies fabled Lake Minnetonka—"The Land of Sky Blue Water"—more than 200 miles of shoreline and plenty of room to set a tack. Nearby, flow the miles of waterway of the Mississippi River, the Minnesota River, and the St. Croix River. Wonderful areas for outboard or launch cruising, with hidden islands and coves to test your spirit of adventure. These aquatic pleasures are but one facet of the many recreational, social and cultural enjoyments you and your family will share when you work at Honeywell's Aeronautical Division in Minneapolis.

ENGINEERING OPPORTUNITIES:

There are openings for qualified personnel in each of these areas where you'll find a Climate for Creativity and job satisfaction working on a wide diversification of missile, space and advanced aircraft.

- Vehicle Structural Design
- Propulsion Systems
- Power Systems
- System Synthesis
- Advanced Gyro Design
- Flight Control & Reference Systems
- Measurements & Display Instrumentation
- Ground Support Equipment
- Human Factors
- Applied Research (in any of the preceding areas)
- Evaluation Laboratory
- Components, Applications and Standards
- Materials Engineering & Physical Chemistry

Select your area and send your résumé or request for information on specific openings to: Mr. Clyde W. Hansen, Technical Director, Aeronautical Division, 2652 Ridgway Road, Minneapolis 40, Minn.

Honeywell

H HONEYWELL *Military Products Group*

To explore professional opportunities in other Honeywell operations, coast to coast, send your application in confidence to: Mr. H. D. Eckstrom, Honeywell, Minneapolis 8, Minnesota. All qualified applicants considered regardless of race, creed, color or national origin.



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Current programs in our expanding Research, Development and Engineering groups provide new and stimulating opportunities in the fields of flight control and space navigation instrumentation and systems.

Opportunities are available now for graduate EE's, ME's and Physicists in:

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LOGICAL DESIGN
SYSTEMS ANALYSIS & SYNTHESIS
ADVANCED MECHANISMS
ADVANCED OPTICAL ELECTRONIC SYSTEMS
PULSE TECHNIQUE
ELECTRONIC DISPLAYS
ADVANCED CONTROL SYSTEMS
MICROMINIATURIZATION
SPECIAL PURPOSE DIGITAL SYSTEMS
BIONICS & MEDICAL ELECTRONICS
SEMICONDUCTOR MATERIALS RESEARCH
LIGHT GENERATION MODULATION & DETECTION

To arrange a confidential interview, forward a brief resume to Mr. John Whitton.

Kollsman Instrument Corporation

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We have succeeded in the development of an entirely new concept for the SUCCESSFUL placement of qualified engineers and scientists. If your present position is frustrating, lacking financial reward or if your employer has failed to utilize your full potential why not communicate with us at once. We now have in excess of 4000 senior positions in the $9,000.00 to $35,000 bracket. Some of these positions offer bonus, stock participation, or profit sharing. For confidential consideration submit your resume in duplicate to Mr. Richard L. Berry (MEMBER IRE). Be sure to indicate your salary requirements and location preferences if any. All search fees and expenses paid by our clients.

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We need men who think for themselves, who are willing to try the unorthodox in a search for technical achievement.

If you
1. Are confident of your engineering ability
2. Like the challenge of difficult projects
3. Can design quality video equipment
4. Believe Electronics can serve as an industrial tool

please send resume to:

General Manager, Electronics Division
Diamond Power Specialty Corp.
Box 415, Lancaster, Ohio

Positions Open

(Continued from page 78A)

puter design, error analysis and operations research. Contact Donald Richman, Assoc. Director of Research, Hazeltine Research Corp., Little Neck 62, N.Y. FAculty 1-2300 (NYC). Positions are at the Plainview, Long Island, laboratory.

ELECTRONIC ENGINEERS & ELECTROMECHANICAL ENGINEERS

ELECTRONIC ENGINEERS with experience in digital system design, digital analysis and design, plus circuitry, simulation, and telemetry. To work on computers, test equipment and instrumentation. ELECTROMECHANICAL ENGINEERS with experience in servos, switches, relays and analog computers. To work on trainers and simulators. Address resume to D. J. Wishart, Aircraft Armaments, Inc., Cockeysville, Maryland.

CHIEF ENGINEER—MILITARY ELECTRONICS

Unusual opportunity. $25,000 starting salary (stock options, etc.) Requires Doctorate in science, electronic engineering or physics. Must have strong engineering administrative abilities. Send complete résumé to Box 2054.

ASSOCIATE OR FULL PROFESSOR

Associate or Full Professor of E.E. Ph.D. required. Interest in either electronics or power fields. Undergraduate and graduate teaching through M.S. research activities desired, but teach-

(Continued on page 84A)

fmc
FOOD MACHINERY AND CHEMICAL CORPORATION

CALIFORNIA

Offers Career Opportunities for challenging assignments in commercial products R&D to:

- **TRANSISTOR CIRCUIT DESIGN ENGINEERS**
- **LOGICAL DESIGN ENGINEERS**

FMC's Central Engineering Laboratories has started a major program using the latest techniques in the design of special purpose computers and memory devices. Experience is desirable in transistor circuitry including digital and linear circuits, logical design, systems design, memory systems, input/output equipment and power supplies.

ELECTRICAL ENGINEERS OR PHYSICISTS

Experienced circuit designers, systems engineers, and specialists, or recent graduates interested in industrial electronics and automation are needed to work on advanced assignments in the design of optimum systems using electronic and mechanical components.

•

FMC's Central Engineering Laboratories' major expansion program requires well-qualified engineers with a high degree of creative imagination to staff our new million dollar facilities in the San Francisco Bay Area. BS required and advanced degrees desirable for these responsible positions.

Interested? Send a resume of your background and professional experience to **E. M. Card, Jr., FMC Central Engineering, 1105 Coleman Avenue, San Jose, California,** or telephone **CYpress 4-8124** for interview appointment.

fmc
FOOD MACHINERY AND CHEMICAL CORPORATION

Putting Ideas to Work

Central Engineering Laboratories

FOOD MACHINERY AND CHEMICAL CORPORATION

61-ICE

at MOTOROLA in PHOENIX:

Beyond a shadow of a doubt



Are *you* beginning to have doubts about achieving the professional goals you set for yourself? Fretting over the lack of opportunity for growth in your present job? If you are, this will interest you: Our philosophy at Motorola is to select engineers and scientists with extreme care. Then we assign them to a Project Group – composed of men whose combined experience and talents cover a broad spectrum. To the group we give challenging state of the art assignments – and the technological tools to solve the problems. By thus affording our professional personnel maximum opportunities for individual growth and achievement, we are convinced – beyond a shadow of a doubt – that we strengthen our *own* ability to maintain leadership in the field of military electronics.

Immediate Opportunities

- Systems Test Equipment Design
- Communications and Navigation
- Systems Analysis and Preliminary Design
- Missile and Space Guidance and Control
- Digital Circuitry Design
- Microwave and Radar
- Reliability and Components
- Solid State Devices

All qualified applicants will receive consideration for employment without regard for race, creed, color, or national origin.

Write Phil Nienstedt (Dept. 701)

MOTOROLA

MILITARY ELECTRONICS DIVISION, WESTERN CENTER

P. O. Box 1417, Scottsdale, Arizona

Motorola also offers opportunities at
Chicago, Illinois, and at Culver City and Riverside, California

SYSTEMS IN TRANSITION

...a scientific challenge

Weapons become obsolete and are replaced, but command and control systems *evolve*. Helping to guide this evolution is the responsibility of The MITRE Corporation. As Technical Advisor to government agencies—notably the Air Force Electronics Systems Division and the Federal Aviation Agency—MITRE is currently engaged in:

...planning and developing command and control systems to net together existing weapons, forces and aerospace vehicles

...designing and implementing an experimental Air Traffic Control System—SATIN (for SAGE Air Traffic Control Integration)

Important work lies ahead in harnessing new capabilities in such fields as electronic reconnaissance and warning, communications and information processing. This requires a wide variety of technical disciplines which must be pursued in an atmosphere of scientific objectivity.

Well-trained men, interested in contributing to vital aspects of national security are invited to join MITRE's growing scientific community. Appointments to the Technical Staff are currently being made in the following areas:

- **Operations Research**
- **System Analysis**
- **Communications**
- **Econometrics**
- **Human Factors**
- **Radar Systems & Techniques**
- **Advanced System Design**
- **Air Traffic Control System Development**
- **Computer Technology**
- **Mathematics**

Openings are also available at MITRE's facility in Montgomery, Alabama.

Inquiries may be directed in confidence to
VICE PRESIDENT—TECHNICAL OPERATIONS

THE MITRE CORPORATION

Post Office Box 208, 4-MU—Bedford, Massachusetts

All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

A brochure more fully describing MITRE *and its activities is available upon request*



(Continued from page 82A)

ing is emphasized. Salary open. Contact Prof. Edwin M. Anderson, Chairman, E.E. Dept., North Dakota State University, Fargo, North Dakota.

DIGITAL COMPUTER PROGRAMMER

Digital Computer Programmer wanted for scientific analysis of biomedical research. Full time, permanent position. Knowledge of mathematics or statistics and programming experience required. Salary depending upon qualifications. Position includes faculty appointment in the School of Medicine. Write to Salomon Rettig, Ph.D., Research Div., Columbus Psychiatric Institute & Hospital, Ohio State University Health Center, 473 W. 12th Ave., Columbus 10, Ohio.

RESEARCH DIRECTOR

Ph.D. to head up research facilities of large capacitor manufacturer. Must have background in all dielectrics. This is top organization position. Replies in confidence. Box 2055.



By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants and to avoid overcrowding of the corresponding column, the following rules have been adopted:

The IRE publishes free of charge notices of positions wanted by IRE members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The IRE necessarily reserves the right to decline any announcement without assignment of reason.

Address replies to box number indicated, c/o IRE, 1 East 79th St., New York 21, N.Y.

ENGINEER

Age 33; married; 1 child. Navy Electronic Technician. BEE. Analytical, imaginative, artistic; not oratorical. 10 years experience with airborne electronic equipment. Seeks firm in Oklahoma, Minnesota, upper New York or Oregon which can express logical product-demand evaluation. Box 3028 W.

ENGINEER

Interested in production. B.S. in E.E., MBA. in Production. Completed Active Duty. Box 3929 W.

EDITOR—PUBLICATIONS MANAGER

B.S. in Physics; 10 years technical writing experience, including 4 years as supervisor; 3 years teaching radio and television repair, laboratory and theory; holder of 1st class radiotelephone license; excellent mathematician; working knowledge of French, German and Russian; expert typist and stenographer. Desires position as

(Continued on page 86A)

Major Systems Programs Pinpoint Opportunities In 26 Areas Of Specialization

Traditional boundaries of defense system definitions are giving way to new, vast-scale operational requirements that may extend from the ocean depths to deep space. ▪ Right now, a number of new programs at Defense Systems Department call for backgrounds ranging from Oceanography to Space Physics. ▪ Openings for graduate engineers at all levels of competence are immediately available on project groups undergoing expansion and new groups currently being organized.

Specific experience is sought in these fields:

Applied Mathematics
Astronomy
Auto Pilots
Classical Mathematics
Communications
Computers
Computer Application Engineering
Data Handling
Guidance Equations
Inertial Guidance
Infra-Red
Nuclear Physics
Oceanography
Operations Analysis
Optics
Propagation Engineering
Radar
Radiation Physics
Sonar
Space Physics
Systems Analysis
Systems Engineering
Systems Synthesis
Systems Test Engineering
Technical Writing
Weapons Systems Analysis

All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

Write in confidence, briefly outlining your education and professional experience to Mr. P. W. Christos, Dept. 53-MG.



DSD DEFENSE SYSTEMS DEPARTMENT
A Department of the Defense Electronics Division

GENERAL ELECTRIC

Northern Lights Office Building — Syracuse, New York



An Invitation
for
PHYSICISTS
MATHEMATICIANS
and
ENGINEERS
from
M. I. T.
INSTRUMENTATION
LABORATORY

The Laboratory's staff of over 1000 under the direction of Dr. C. Stark Draper is engaged in the conception and perfection of completely automatic control systems for the flight and guidance of missiles and space vehicles. Its achievements include the Navy Mark 14 Gunsight, the Air Force A-1 Gunsight, Hermetic Integrating Gyros (HIG), and the Ship Inertial Navigation System (SINS). The Laboratory developed basic theory, components and systems for the Air Force THOR and later, the TITAN missile.

The Laboratory also developed the Navy's POLARIS guidance system. Studies for NASA are currently being carried out.

Research and Development opportunities exist in:

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- ASTRONAUTICS
- HIGH PERFORMANCE SERVOMECHANISMS
- POWER SUPPLIES AND MAGNETIC AMPLIFIERS
- DIGITAL AND ANALOG COMPUTERS
- ELECTRO-MECHANICAL COMPONENTS
- TRANSISTOR CIRCUITRY AND PULSE CIRCUITRY
- RESEARCH, DESIGN AND EVALUATION OF GYROSCOPIC INSTRUMENTS
- COMPUTER PROGRAMMING AND SIMULATOR STUDIES
- LOGICAL DESIGN
- AND IN MANY OTHER AREAS

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HOWARD F. MILLER, *Personnel Officer*

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• Graduate courses may be taken for credit while earning full pay. • U. S. Citizenship required.
All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.



Positions Wanted

By Armed Forces Veterans

(Continued from page 84A)

editor of electronics publication or as supervisor in publications section of electronic equipment manufacturer. New York City area preferred. Box 3930 W.

PATENT ADMINISTRATION

Age 40. Engineering and Law degrees. 9 years experience prosecuting and preparing patents in the complex electronics arts in radio, radar, TV, scopes, UHF, VHF fields. Desires position in small company or law firm anywhere in U.S. Box 3931 W.

ENGINEER—PILOT

Age 27; BSEE, 1961; 6 years experience piloting USAF all-weather interceptors; presently Assistant Operations Officer, Instrument Flight Examiner, and Instructor Pilot in F-102A and T-33A Aircraft of an ADC Squadron; 1500 jet hours. Desires position as aircrew member testing airborne electronic equipment. Box 3932 W.

DIGITAL COMPUTER ENGINEER

MEE. Experienced in all phases of digital computer engineering, including significant supervisory, circuit design, logical design, system development. Extensive magnetic core experience. 12 years experience, including sales, executive, college teaching. Patents. Desires stimulating, forward looking work. Box 3933 W.

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10 years experience in weapon and automation systems R & D. Desires managerial position in small, technically oriented company. Available in June. Resume upon request. Box 3934 W.

ELECTRONICS TECHNICIAN

Graduate RCA Institutes V7 course. Age 28, married. Experience in repair of spectrophotometers, pH meters, hemophotometers. titrimeters, G. C., etc. Knowledge of Danish, German, French and Spanish. Seeks position with biomedical mfr. as technician or representative. Willing to relocate to Denmark, Sweden or in U.S. Box 3941 W.

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Desires free-lance technical writing assignments for short term contracts. Prefer Southern California area. Age 30. 10 years experience in military and civilian electronics. 2 years experience in technical writing. Active member in IRE and STWP. Résumé upon request. Box 3942 W.

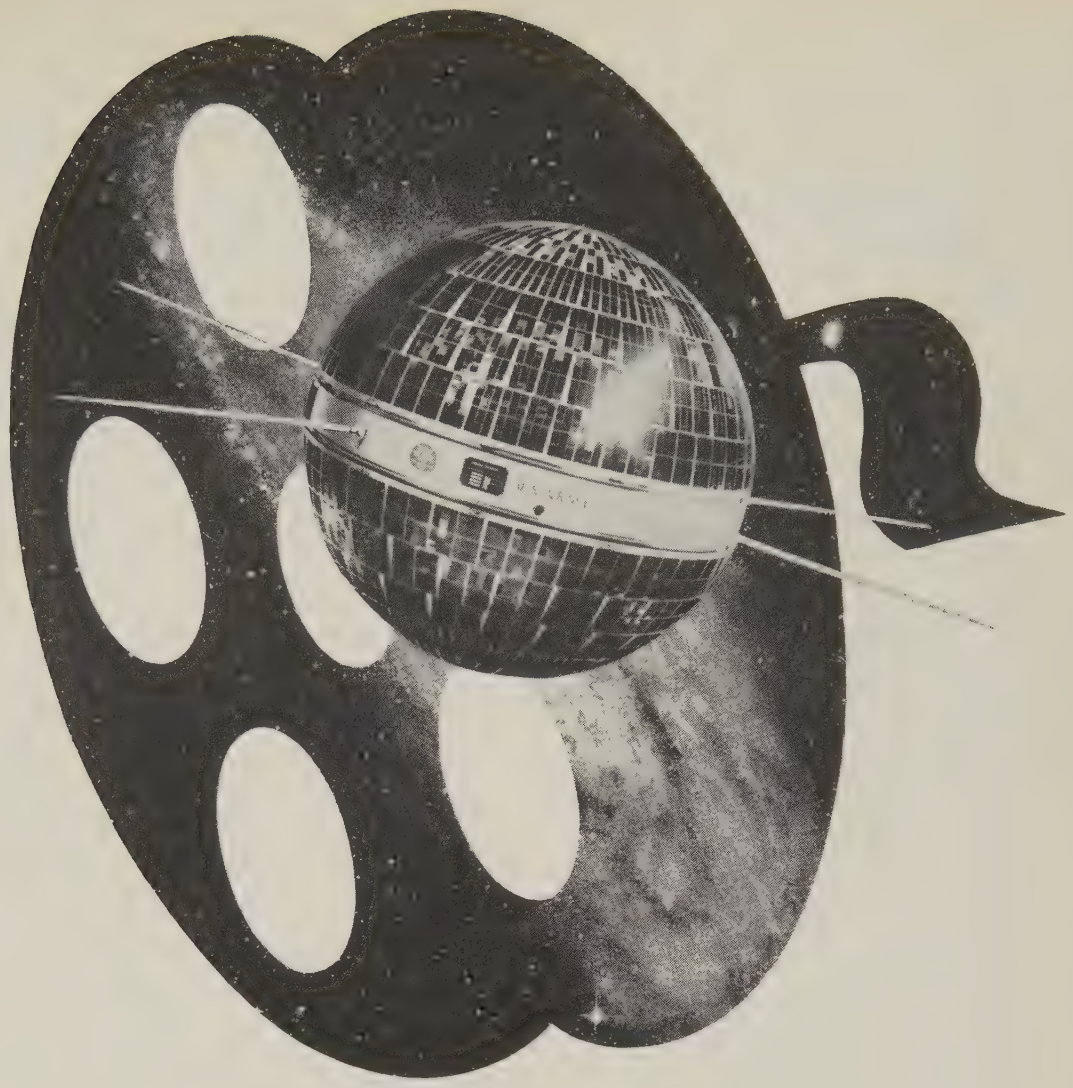
ENGINEERING MANAGER

Age 36. BSEE., MSEE. Completed course credits for Ph.D., EE. Control, communications and systems engineering. Teaching experience and business training. Presently manager of small consultant team to U. S. Army. Will consider overseas assignment. Box 3943 W.

ENGINEER

Communications oriented. Age 33. 15 years experience in communications and allied fields, with some broadcast experience. Desires challenging position in this field in either development or application. Feeling of accomplishment more important than salary or location. Box 3952 W.

(Continued on page 88A)



LP Record—Stellar Style

The message from Courier is just one of the challenges offered to you at PHILCO Western Development Laboratories, whose long record in space communications achievement merely presages the adventure ahead.

From the earliest plans to invade space, PHILCO Western Development Laboratories has played a vital role in satellite vehicle instrumentation, still but *part* of its contribution to space communications. From this newest electronics center on the San Francisco Peninsula comes a continuing flow of advanced missile tracking, range and data processing instrumentation.

Added research projects and growing programs assure *you* a long and rewarding career as a member of the PHILCO Western Development Laboratories. What you think and what you do can be unhampered and uninhibited. Personal recognition and advancement promptly follow performance, with monetary rewards to match. Northern California provides an affluent climate for living, as PHILCO Western Development Laboratories provides a stimulating climate for working. For information on careers in electronic engineering, please write Mr. W. E. Daly, Dept. R-7.

All qualified applicants for employment will be considered without regard to race, creed, color, or national origin; U. S. citizenship or current transferable Department of Defense clearance required.

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"The company is interested in NEW ways of doing things"..."work is carried on above the average level"..."circuit design here goes all the way from DC through microwave"—

—so say Engineers who have joined Sanders Associates in the past few months.

Such progressive philosophy has led to this young company's growth from 11 engineers to 1800 employees in only 10 years, with a current contract backlog of over $50 million.

Still further expansion is planned for pioneering programs in many advanced areas including phased array radar, pulse doppler radar systems, space radar and communications systems.

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Opportunities are available now for:

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Requires extensive microwave systems design background and ability to direct engineering activities in microwave systems for radar and missile applications — standard components and stripline techniques including antenna systems and stripline modules. Must be capable of both technical and administrative supervision.

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To provide technical guidance at the Corporate level on a wide variety of transistor circuit design problems. Requires ability to design detailed circuits rapidly.

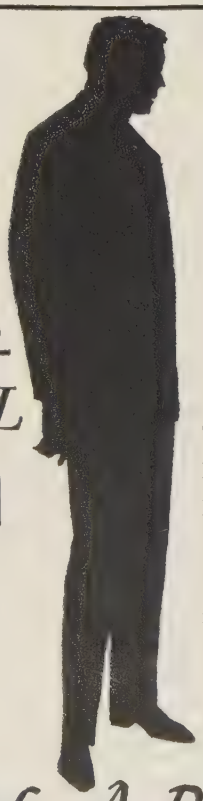
RECEIVER DESIGN ENGINEERS
3 to 8 years experience. For design and development of receivers for military applications. Experience should include design of low noise front ends, IF strips, AGC circuitry and application of image rejection techniques. All transistorized. BS in EE or Physics.

TRANSMITTER DESIGN ENGINEERS
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By Armed Forces Veterans

(Continued from page 86A)

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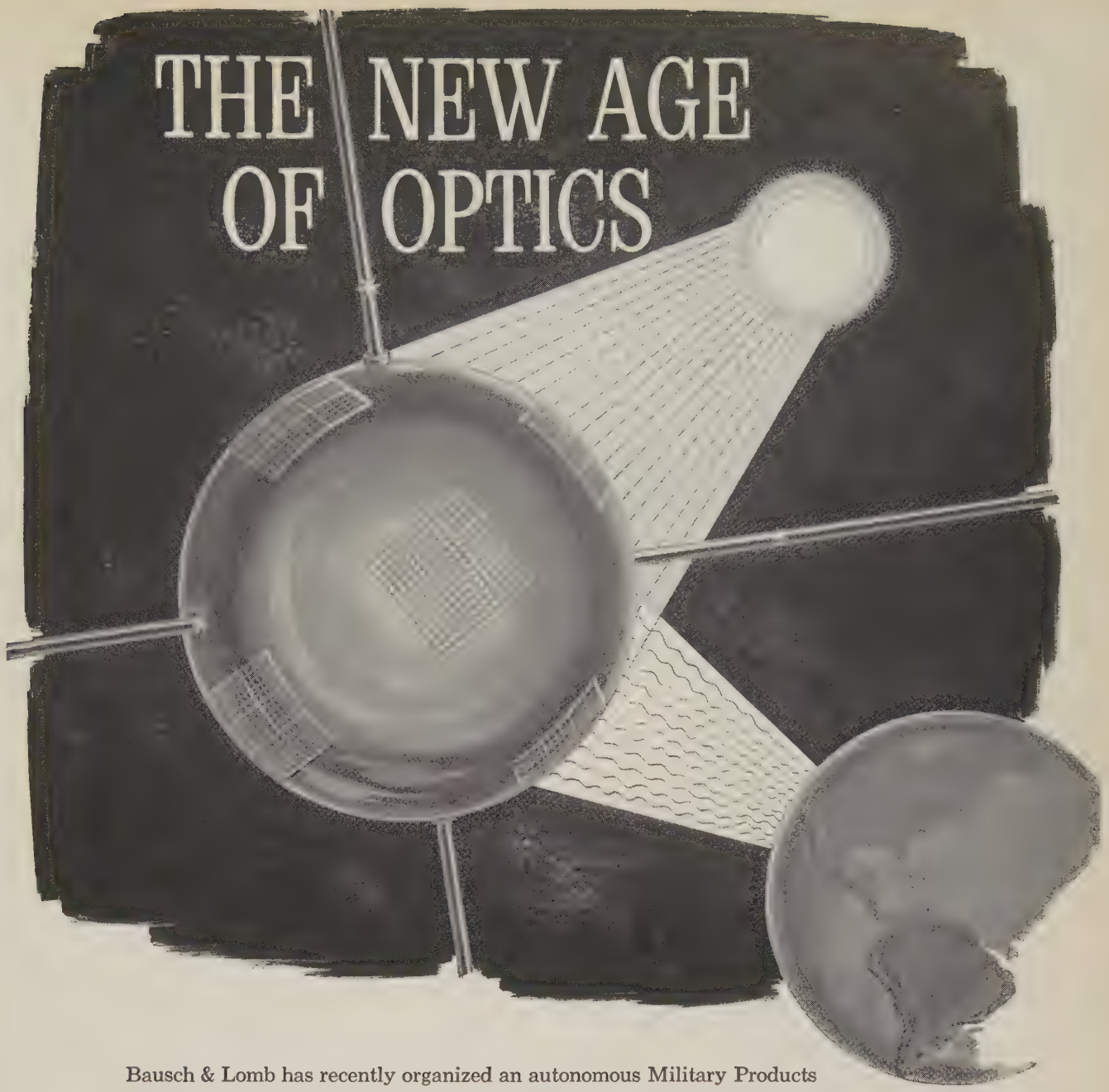
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(Continued on page 90A)

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By Armed Forces Veterans

(Continued from page 88A)

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Professional Group Meetings

(Continued from page 72A)

San Francisco—April 5

"Models, Devices and Components," J. G. Linville, Stanford University.

Component Parts

Los Angeles—April 10

"Automatic Testing of Components, Measurement Techniques," H. Stansch, Hewlett-Packard Co., Palo Alto.

"Automated Digital Systems for Component Measurement," W. Gross, Electro Instruments, Inc., San Diego.

Washington—March 8

"Ceramic Devices," Dr. S. W. Tehon, General Electric Co., Syracuse, N. Y.

Electron Devices

Boston—April 13

"Research and Development in Magnetic-Film Memories," Dr. D. O. Smith, Lincoln Labs., MIT, Lexington.

Los Angeles—April 11

"Methods of High Speed Photography," G. Clark, S.T.L., Hawthorne, Calif.

San Francisco—April 5

"The Plasma Diode," Dr. R. Fox, Lawrence Radiation Lab., Livermore, Calif.

Electronic Computers

Baltimore—April 3

"Application of Magnetic Films to Computers," W. W. Davis, Remington Rand Univac, Minneapolis, Minn.

(Continued on page 92A)



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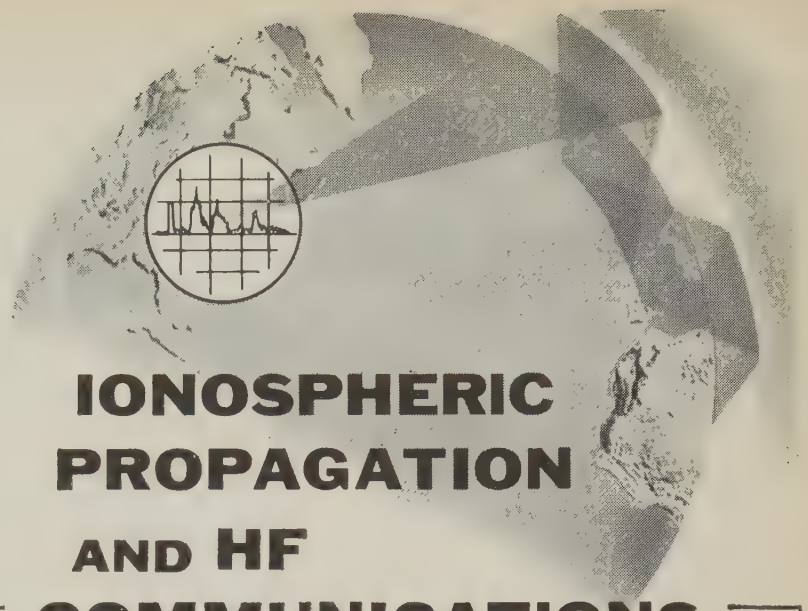
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SENIOR ELECTRONIC ENGINEERS

Advanced degree in E.E. preferred. Must be familiar with conventional pulse circuit designs and applications. Technical background should include substantial experience in data process and data recovery systems using both analog and digital techniques. Knowledge of principles and application of modern information theory including correlation techniques helpful. Will be responsible for the design of sub-systems.

JUNIOR ELECTRONIC ENGINEERS

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Palo Alto, Calif.

Professional Group Meetings

(Continued from page 90A)

Baltimore—January 24

"Application of Microwave Techniques to Computers," R. L. Wigington, Dept. of Defense, Washington, D. C.

Baltimore—November 22

"Majority and Minority Logic," K. C. Wehr, Westinghouse Electric Corp., Baltimore, Md.

Binghamton—April 17

"ANEBA—a Character Sensing Development Device," D. C. Groce, IBM Corp., Endicott, N. Y.

Los Angeles—April 19

"Interrupted Stochastic Processes," Dr. R. Bellman, Rand Corp., Santa Monica, Calif.

Los Angeles—April 13

"Burroughs B 5000 Data Processing System," N. Kruter, D. T. Kielty, and A. B. Gerlach, Burroughs Corp., Pasadena, Calif.

Los Angeles—March 16

"Switching Time of Tunnel Diodes," O. S. Goda, RCA, Van Nuys, Calif.

"Tunnel Diodes for Computers," J. A. Connell, RCA, Van Nuys, Calif.

Philadelphia—April 20

"ALGOL-60: An Algebraic Language for Computers," Dr. A. J. Perlis, Carnegie Inst. Tech., Pittsburgh, Pa.

"Application of Fortran to the S-2000 Computer," Dr. S. Rosen, consultant on electronic computers.

San Francisco—April 25

"Philosophy and Practice of Display Systems, Both Military and Commercial," R. C. Schneider, Advanced Systems Div., IBM, San Jose, Calif.

Washington, D. C.—May 3

"Automated Real Time Error Control," E. C. Joseph, Remington Rand Univac, St. Paul, Minn.

Engineering Management

Baltimore—April 13

"Operations Research for Engineering Managers," G. Klotsch, Chesapeake and Potomac Telephone Co., Baltimore, Md.

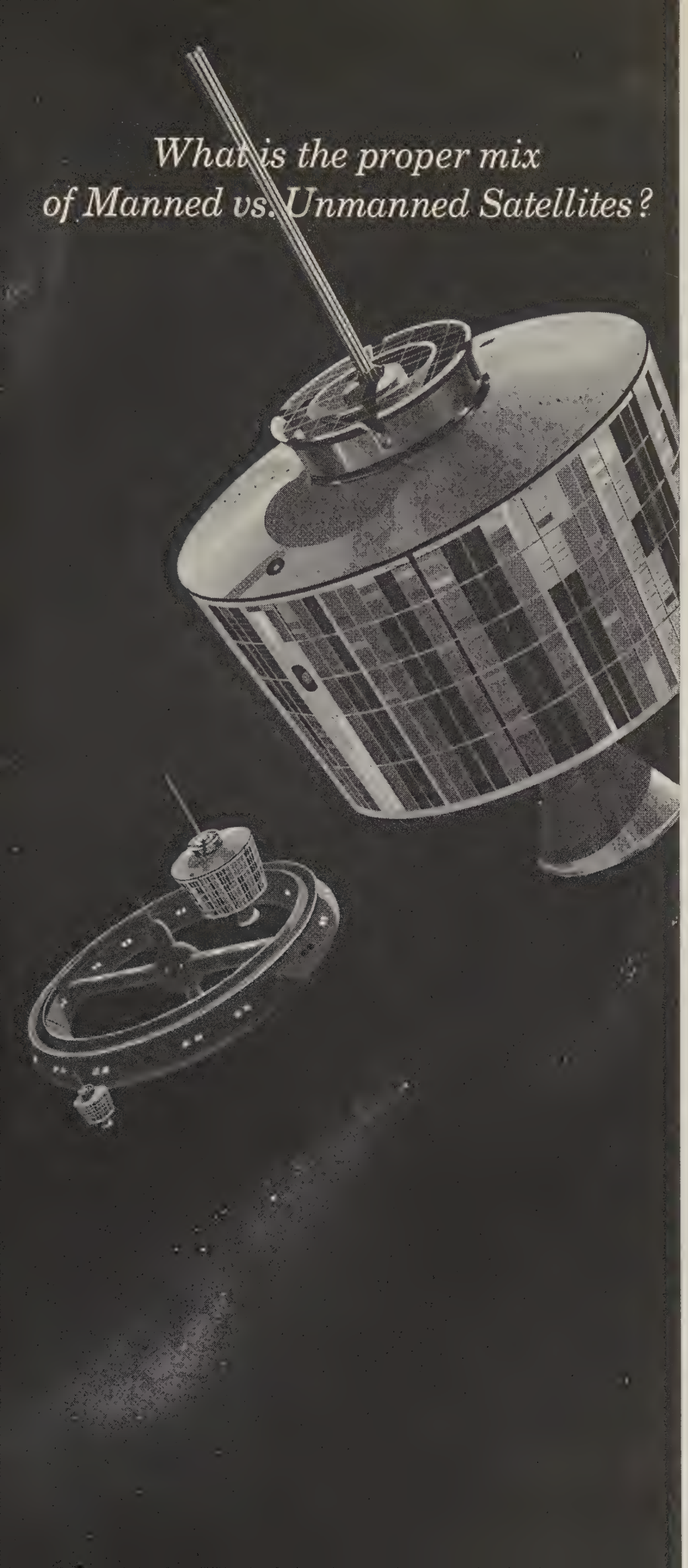
Baltimore—March 9

"The Transition from Professional Engineer to Professional Manager," F. G. Barry, Bendix Radio, Baltimore, Md.

Baltimore—January 6

"Engineered Breakthroughs," T. Clark, Westinghouse Air Arm Div., Baltimore.

(Continued on page 94A)



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Professional Group Meetings

(Continued from page 92A)

Boston—April 6

"Managing a Professional Society," Dr. R. L. McFarlan, Past President, IRE.

Boston—February 23

"The Nature of Command and Control," Maj. Gen. K. P. Bergquist, USAF.

San Francisco—March 8

"The Technical Entrepreneur," Dr. J. Melchor, ME Labs.

ENGINEERING WRITING AND SPEECH

Boston—April 4

"Communication Between Engineering and Production," F. V. Alla, General Radio; R. D. Eames, Raytheon.

Northern New Jersey—April 18

"How to Prepare a Speech," Dr. H. Tichy, Hunter College.

Northern New Jersey—February 8

"Should Engineers do Their Own Writing?" (Debate) J. Chapline and T. O'Neill, Philco Corp.

(Continued on page 96A)

ASSOCIATE EDITORS

To scan foreign technical literature, select articles and prepare brief summaries. Basic competence in 2 or more of the following fields is mandatory:

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MECHANICS DIVISION (Los Angeles). Responsibilities of the Propulsion, Engineering Mechanics, and Aerosciences Laboratories within this division include: analyzing and evaluating performance of rocket engines, propellants and propulsion subsystems and components; conception, design, development, and evaluation of ballistic missile and space vehicle systems; development and implementation of structural, dynamic, aerodynamic, and re-entry vehicle research and development concepts for both ballistic missile and space vehicle programs; and development of new subsystems for missile and spacecraft applications.

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ELECTRONICS DIVISION (Los Angeles). The Communication, Electromechanical, Guidance, and Space Physics Laboratories of this division are responsible for analysis, design, and development of advanced guidance, control, and communications systems for ballistic missiles and space vehicles—from applied research to electronic product and ground support equipment design. Disciplines include the physical, electronic, and electromechanical aspects of guidance, tracking, control, communication, and computer systems, geophysics, and space physics.

RESEARCH LABORATORY (Los Angeles and Canoga Park, California). Fields of interest include: physical studies of gaseous electronics, artificial meteors, reactor kinetics, microwave electronics; studies of quantum chemistry, thin film applications, electron and ion dynamics, and theoretical physics; heavy particle studies; ion propulsion research including neutralization and beam diagnostics, emitters, acceleration and ion optics, and engine design.

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ELECTROMAGNETIC SYSTEMS DIVISION (Canoga Park, California). The Radio Physics and Signal Equipment Laboratories of this division are engaged in developing advanced communication, radio direction finding, electro-optical, and penetration and reconnaissance systems; and in investigating advanced signal processing, electronic and anti-submarine warfare techniques.

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COLUMBUS DIVISION
NORTH AMERICAN AVIATION

Professional Group Meetings

(Continued from page 94A)

San Francisco—March 21

Business meeting.

Instrumentation

San Francisco—April 11

"Nanosecond Pulse Techniques," D. Dunwoodie, Wiltron Co., Palo Alto, and Z. Tarczy-Hornach, Eldorado Electronics, Berkeley.

Washington, D. C.—May 1

Underwater Instrumentation—Panel Discussion, Dr. L. F. Whicker, David Taylor Model Basin, Carderock, Md.

"Underwater Acoustic Measurements," C. H. Barrett, The Electro Nuclear Systems Corp., Bethesda, Md.

"Deep Towed Oceanographic Instrumentation," W. M. Ellsworth, Pneumodynamics Corp., Bethesda, Md.

"Remote Controlled Underwater Vehicles," W. Frienmouth, Vitro Labs., Silver Spring, Md.

Microwave Theory and Techniques

Baltimore—May 3

"Recent Developments in Traveling-Wave Antennas," F. J. Zucker, Air Force Cambridge Research Lab.

Baltimore—March 15

"Calculated Scalor Diffraction Patterns for a Spherical Array Antenna," H. E. Schrank, Westinghouse Electric Co., Baltimore, Md.

"Computed Characteristics of Beams Formed by Large Cylindrical Arrays," R. E. Willey, Bendix Radio, Towson, Md.

"Characteristics of Beam Forming from Large Planar Arrays," Dr. F. C. Ogg, Johns Hopkins University, Radiation Lab., Baltimore, Md.

Los Angeles—April 13

"Relativity Satellite," Dr. John Walsh, Hughes Research Lab., Malibu, Calif.

Northern New Jersey, Long Island, and New York—April 19

The Electronics Industry in Space (Panel)—Moderator: W. M. Thames, Jr., Advent Management Agency, Fort Monmouth, N. J.; Panel: J. R. Pierce, Bell Telephone Labs., Murray Hill, N. J.; P. R. Adams, IT&T Corp., New York, N. Y.; R. L. Clark, Dept. of Defense, Washington, D. C.

Washington, D. C.—April 11

"Spectrum Utility in Space Communication," C. T. McCoy, Philco Corp., Philadelphia.

Military Electronics

Los Angeles—March 8

"Power Systems for Space Vehicles,"

(Continued on page 98A)



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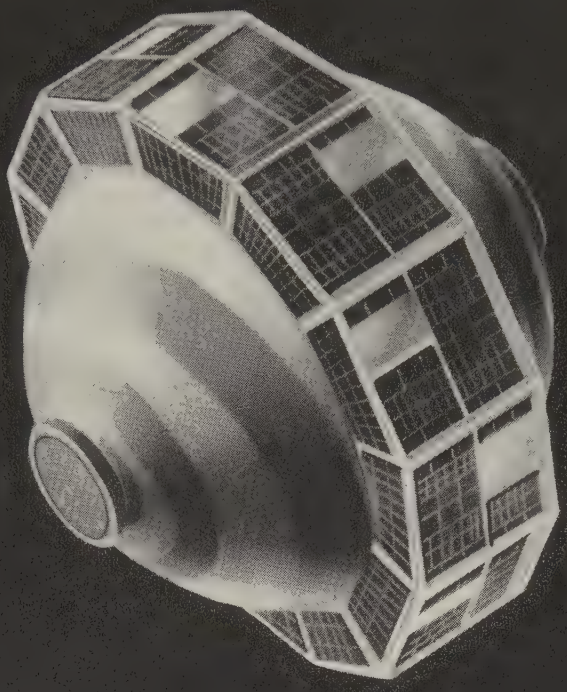
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Professional Group Meetings

(Continued from page 96A)

Mr. R. L. Sohn, Space Technology Labs., Los Angeles, Calif.

Los Angeles—January 25

"Atomic Clocks and Frequency Standards," Dr. D. J. Farmer, Clauser Technology Corp., Torrance, Calif.

Philadelphia—April 27

"The Mauler Weapon System," H. D. Mitman, Army Rocketry Guided Missile Agency, Huntsville, Ala.

Display of components and system model.

Rome-Utica—November 15

"Optical Maser," Dr. R. C. Mack, Hughes Aircraft Co.

Nuclear Science

Los Angeles—April 18

Films on three nuclear reactors.

Product Engineering and Production

Philadelphia—April 12

Panel Moderator—Dr. G. Auth, Villanova University.

"Packaged Micro Modules," D. Levy, RCA, Somerville, N. J.

"Applied Photography" D. Spear, Eastman Kodak Co., Rochester, N. Y.

"Abrasive Machinery Applications," J. Ennis, S. S. White Dental Mfg. Co.

"Trends in Ultrasonic Welding and Soldering," R. S. Foote, Raytheon Co.

San Francisco—April 19

"Semiconductor Reliability, Project Virtue," W. P. Cole, Lansdale Tube Co., Div. of Philco Corp.

Radio Frequency Interference

Rome-Utica—November 2

R. Miller, Chairman, spoke about the future plans of the Chapter.

Reliability and Quality Control

Los Angeles—April 17

"Reliability in Bearings," S. Matheson, Bearing Inspection Co., Huntington Park, Calif.

Space Electronics and Telemetry

Los Angeles—April 18

"A New Concept in Low Level Data Acquisition," R. W. Guldstrand and W. Stanke, Electro-Logic Corp., Venice, Calif.

(Continued on page 106A)

Increased technical responsibilities in the field of range measurements have required the creation of new positions at the Lincoln Laboratory. We invite inquiries from senior members of the scientific community interested in participating with us in solving problems of the greatest urgency in the defense of the nation.

RADIO PHYSICS and ASTRONOMY

RE-ENTRY PHYSICS

PENETRATION AIDS DEVELOPMENT

TARGET IDENTIFICATION RESEARCH

SYSTEMS: Space Surveillance
Strategic Communications
Integrated Data Networks

NEW RADAR TECHNIQUES

SYSTEM ANALYSIS

COMMUNICATIONS: Techniques
Psychology
Theory

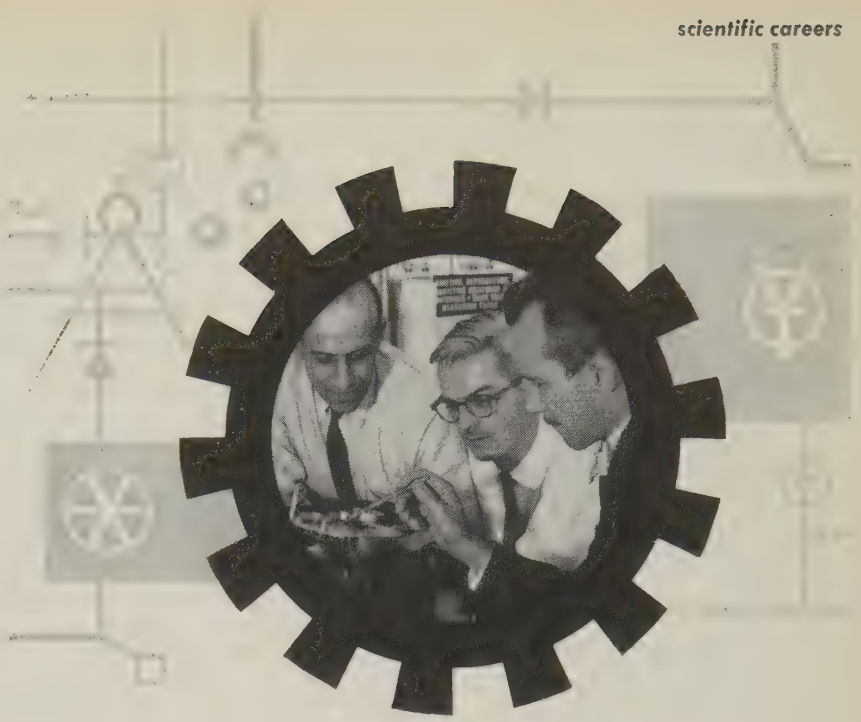
INFORMATION PROCESSING

SOLID STATE Physics, Chemistry, and Metallurgy

A more complete description of the Laboratory's work will be sent to you upon request.

All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

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If you are interested in learning more about career opportunities at HRB-Singer, write George H. Rimbach, Supervisor of Personnel, Dept. R-3.

**for technical data write Dept. MSD.*

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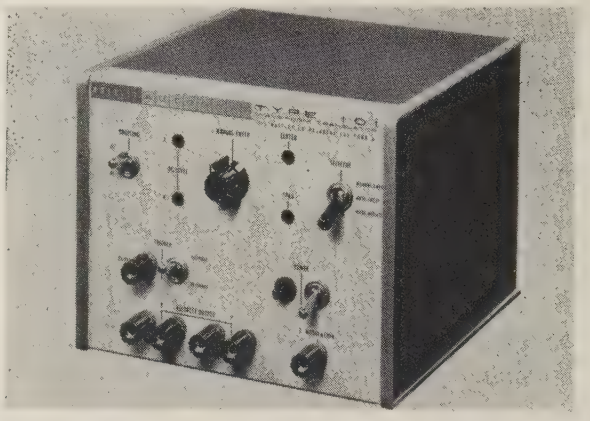
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NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

Waveform Translator

One of the new instruments at the recent IRE Show in New York was the Autograf Type 101 Waveform Translator developed by **F. L. Moseley Co.**, 409 N. Fair Oaks Ave., Pasadena, Calif. This translator operates with an *X-Y* recorder to produce a permanent inked record of a high speed repetitive function displayed on an oscilloscope.



Representative functions which can be translated by the Autograf Type 101 include magnetic hysteresis loops, volt-ampere characteristics and Lisajous figures. The translator is particularly suited for such applications as inter-connecting dc analog simulation equipment with analog equipment operating at high frequencies, or recording the actual operating characteristics of a production item to give a permanent record of the item's acceptable performance.

Operation of the translator is based on recurrent simultaneous sampling of both vertical and horizontal oscilloscope deflection plate voltages at intervals equal to, or very nearly equal to, the waveform period. These sample signals, which result from normal oscilloscope operation, are fed to the translator's high impedance input and each signal is then applied to an individual sampling clamp.

An amplitude comparator equates the signal to a slowly varying reference voltage derived from a ramp generator, and the resulting strobe pulse is used to drive the clamps. As the strobe traverses the trace, the outputs of the *X* and *Y* clamps are accurate measurements of the instananeous coordinates of the scanning strobe point. These dc signals are applied to the axes of the *X-Y* recorder to produce a permanent inked record of the waveform. For identification purposes, the strobe pulse is also transmitted to the intensity, or *Y*-axis, of the oscilloscope to form a bright spot on the trace at the point being sampled. The strobe features may also be used to "blank" the trace.

The translator also provides a manual sampling mode. Strobe position is selected by varying a single-turn potentiometer which controls the reference voltage applied to the amplitude comparators. In either mode, the inked records may be produced to any scale and positioned anywhere on the graph paper by adjustment of the recorder range and zero controls. To minimize the problems of drift and bounce created by unregulated oscilloscope power supplies, the translator provides a switch for selecting either direct dc or capacitive ac coupling.

If desired the translator can be operated directly from the test device without an intermediate oscilloscope. In this case, the electrical signal characteristics must be of the same form and amplitude as supplied by an oscilloscope. In this case, the electrical signal characteristics must be of the same form and amplitude as supplied by an oscilloscope, and an external trigger signal is required.

(Continued on page 102A)



The Making of History was not only His Privilege

... It was His Goal

If you are an advanced degree physicist, scientist or electronic management engineer who seeks to shape air and space vehicles to their unique environmental problems rather than stretch existing designs for marginal success, you are needed at McDonnell.

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Over 100 O.E.Ms have standardized on
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Thermostatic DELAY RELAYS
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Actuated by a heater, they operate on A.C., D.C., or Pul ating Current.
Hermetically sealed. Not affected by altitude, moisture, or climate changes.
SPST only—normally open or closed.
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TYPES: Standard Radio Octal, and 9-Pin Miniature . . . List Price, $4.00.
AMPERITE DELAY RELAY
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NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

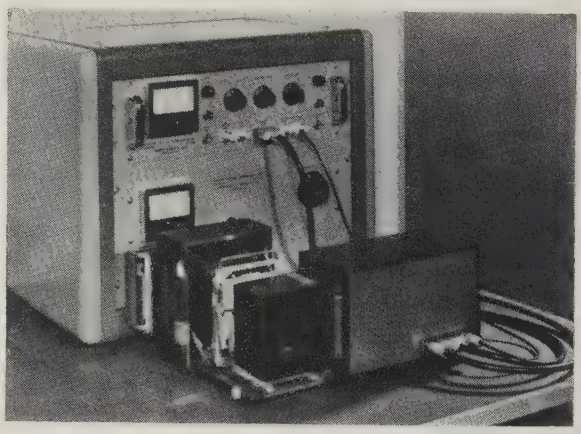
(Continued from page 100A)

Circuitry is transistorized and uses a Zener diode controlled power supply. The unit is suitable for either cabinet or rack mount and is constructed for maximum operating convenience with all operating controls located on the front panel.

Further information on the Type 101 may be obtained from the firm.

Kerr Cell Camera System

A new Kerr Cell Instrumentation Camera System, model KSC-51/A, has been announced by **Electro-Optical Instruments, Inc.**, 2612 East Foothill Blvd., Pasadena, Calif. The capability of this firm's line of ultra high speed Kerr cell instrumentation has been extended by the addition of a trigger pulse generator to the control unit circuitry of its present KSC-51 model. An external pulse generator was formerly required to initiate the Kerr cell shuttering action.



The pulse generator of the new KSC-51/A permits operation from an external low voltage trigger source, as well as from an internal 60 cps source. The trigger pulse generator has three output pulses with the following characteristics: a 50-volt pulse from a high impedance source which can be utilized to provide time-base generation; a fixed 300-volt pulse which provides Kerr cell triggering action into a 50-ohm load; and a 100 to 300-volt variable output pulse which is available for initiating other phenomena or instrumentation.

For a large number of applications the KSC-51/A internally-supplied, pulse generator can be used to initiate shuttering action directly without the use of higher voltage trigger pulses necessary in applications where extreme precision in the triggering of Kerr cell shuttering action is not required. The 300-volt trigger keeps triggering delay times below 100 nanoseconds, while the jitter in the KSC-51/A Kerr cell shuttering action is no more than 15 nanoseconds.

Applications where such triggering characteristics are adequate include plasma and shock tube studies, and hypervelocity and impact phenomena research.

The addition of TG-100 Pulse Generator as an accessory to the new KSC-51/A model results in a complete instrument suitable for application where extreme time resolution is required. The TG-100 Pulse Generator, initiating Kerr cell shuttering directly, reduces trigger jitter to below one nanosecond and delay in initiation of triggering action to times on the order of 40 nanoseconds. The complete system, utilizing the new KSC-51/A camera system and EOI's TG-100 Pulse Generator, has been designated the KSC-51/B Kerr Cell Camera System.

Used alone, the TG-100 is useful as a pulse generator for other applications due to its ability to deliver a 100-ampere pulse of 0.1 microsecond duration into a 50-ohm load.

The most compact X-band Magnetron available to provide 200 watts peak power or 20 watts CW



ACTUAL SIZE

What requirements are most important in airborne beacons? High reliability, excellence in package design, efficiency, and the highest obtainable stable output.

It is not a coincidence that Microwave Associates' MA-231 and MA-232 X-band magnetrons have just these features. Our magnetron experience has stressed design of small tubes for high reliability, military airborne applications.

These new tubes, for use at frequencies between 7500 and 10,000 Mc provide the highest available power in an already-proven package . . . compact, rugged, and ideal for beacon applications. They weigh 11 ounces.

For beacon, transponder, airborne navigation, or proximity detection uses . . . there is no smaller, more efficient magnetron.

Individual data sheets on the MA-231 and MA-232 will be sent on request.

TYPICAL OPERATING PARAMETERS

Type*	Freq. Range (Mc)	Peak Power Output (Min.)	Pulse Width (μs)	Duty Cycle Du	Peak dc Anode Voltage eb (kv)	Peak dc Anode Current ib (a)
MA-231A	7500-8800	200 w	1.0	0.05	1.00	0.750
MA-232A	8800-10,000	200 w	1.0	0.05	1.00	0.750
MA-231B	7500-8800	20 w	CW	1.0	0.93	0.055
MA-232B	8800-10,000	20 w	CW	1.0	0.93	0.055

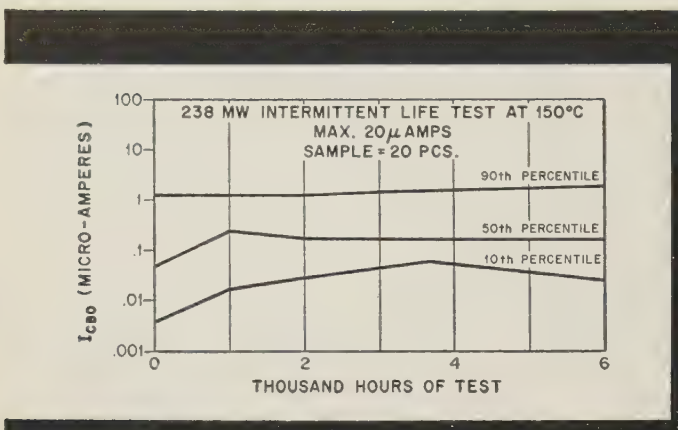
*Fixed Tuned

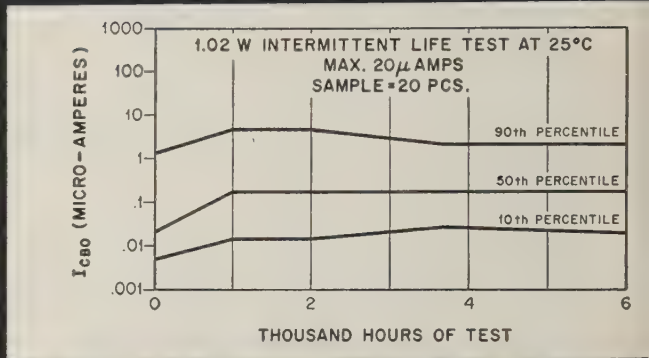
MICROWAVE ASSOCIATES, INC.
ELECTRON TUBE AND DEVICE DIVISION

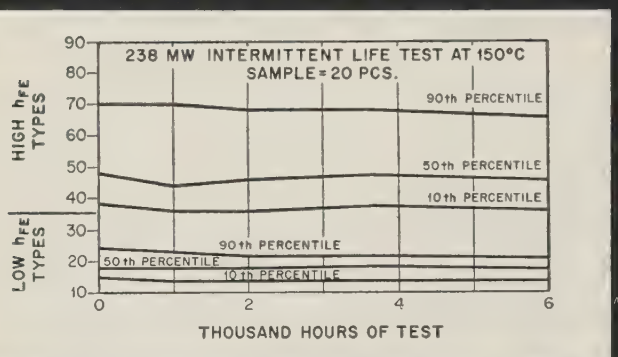
Burlington, Massachusetts • BRowning 2-3000
Western Union Fax • TWX: Burlington, Mass. 942

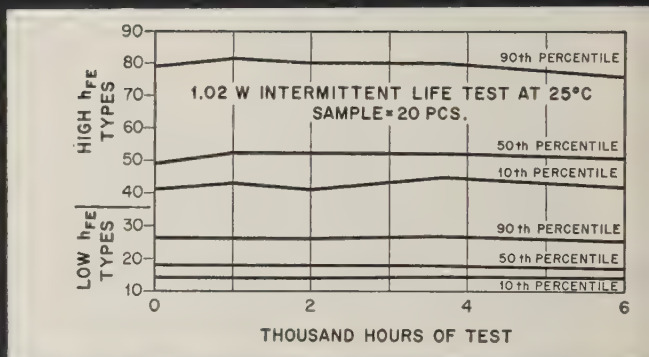
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The industry's most thoroughly characterized and medium power silicon Mesa transistors...2N497A,









Absolute Maximum Ratings (25°C)

		2N497A	2N498A	2N656A	2N657A	
Voltages						
Collector to Base	V_{CBO}	60	100	60	100	volts
Collector to Emitter	V_{CEO}	60	100	60	100	volts
Emitter to Base	V_{EBO}	8	8	8	8	volts
Temperatures						
Storage	T_{STG}	−65 to 200°C				
Operating Junction	T_J	−65 to 200°C				

Total Dissipation
Free Air @ 25°C — 1 watt*
Case Temperature @ 25°C — 5 watts**

*Derate 5.72 mw/°C increase in ambient temperature above 25°C
**Derate 28.6 mw/°C increase in case temperature above 25°C

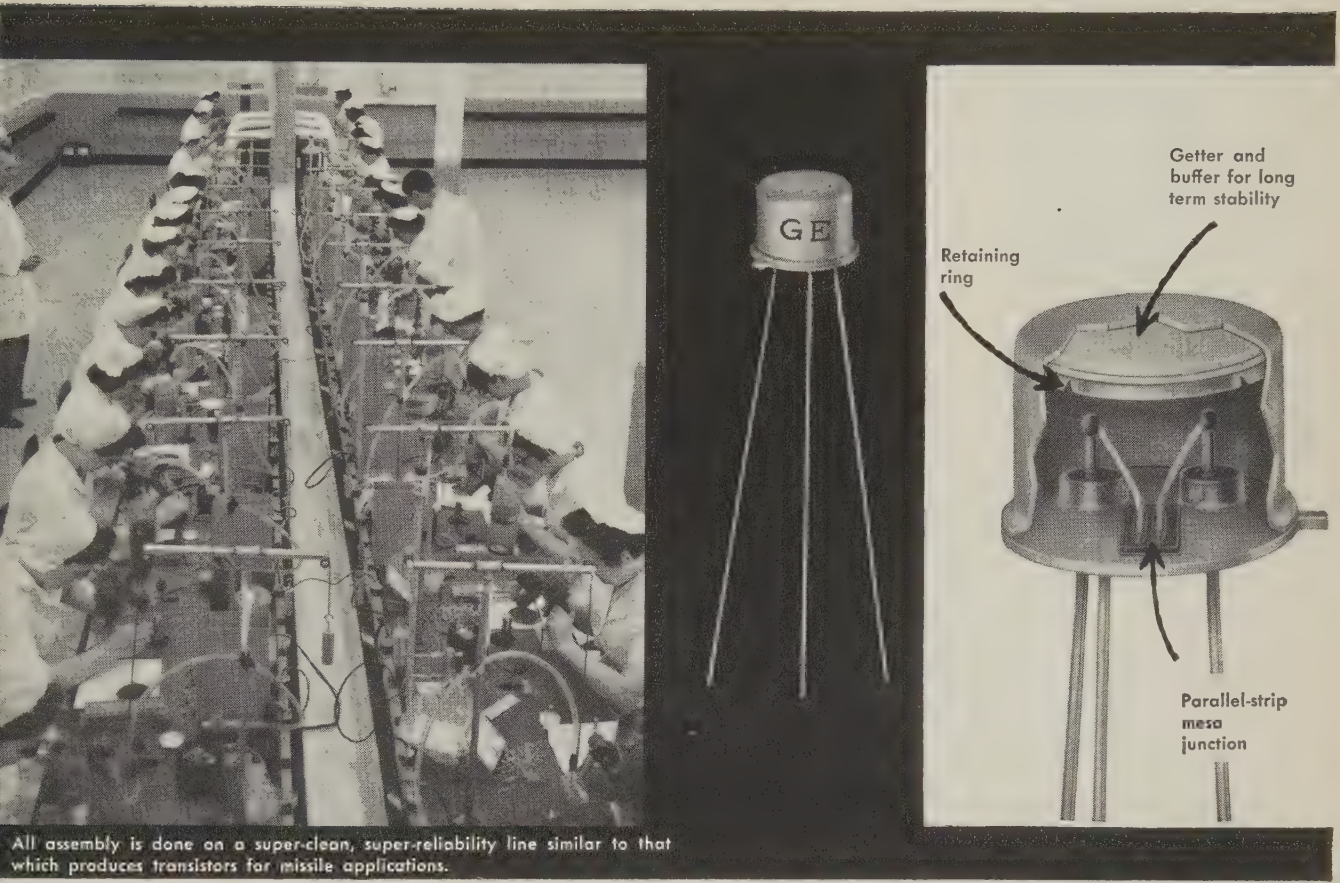
Electrical Characteristics (25°C) unless otherwise specified

D-C Characteristics		2N497A Min.	2N497A Max.	2N498A Min.	2N498A Max.	2N656A Min.	2N656A Max.	2N657A Min.	2N657A Max.	
Collector to Base Voltage (I_C=100 μa, I_E=0)	V_{CBO}	60		100		60		100		volts
Collector to Emitter Voltage (I_C=250 μa)	V_{CEO}	60		100		60		100		volts
Collector to Emitter Voltage (I_C=16 ma)	V_{CEO}	60				60				volts
Collector to Emitter Voltage (I_C=10 ma)	V_{CEO}			100				100		volts
Emitter to Base Voltage (I_E=250 μa, I_C=0)	V_{EBO}	8		8		8		8		volts
Forward Current Transfer Ratio* (I_C=200 ma, V_{CE}=10V)	h_{FE}	12	36	12	36	30	90	30	90	
Base Input Resistance* (I_B=8 ma, V_{CE}=10V)	h_{IE}		200		200		200		200	ohms
Saturation Resistance* (I_B=40 ma, I_C=200 ma)	r_{CE} (sat)		10		10		10		10	ohms
Cutoff Characteristics										
Collector Current (I_E=0, V_{CB}=30V)	I_{CO}		10		10		10		10	μa
Collector Current (High Temperature) (I_E=0, V_{CB}=30V, TA=150°C)	I_{CO}		250		250		250		250	μa

*Pulse Test: 300 μsec. 2% Duty Cycle

Specifications also available for 2N497,498, 2N656,657 mesa transistors

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98A, 2N656A, 57A...come from General Electric



All assembly is done on a super-clean, super-reliability line similar to that which produces transistors for missile applications.

Positive internal atmospheric control achieved through the use of General Electric's buffered-sieve encapsulation technique, higher power dissipation with lower saturation resistance and lower input impedance are important features of this line of top quality one to five watt audio switches. Especially well suited for either high level linear amplifier or switching applications, these are the industry's most thoroughly characterized and tested medium power silicon double diffused NPN transistors available today. Just take a look at the extended life test charts illustrated for convincing evidence of long term stability and reliability.

Semiconductor Products Department, Section 54G96, Electronics Park, Syracuse, New York.

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ATR PRODUCTS FOR MODERN LIVING



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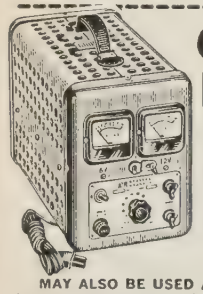
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MODELS
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Designed for testing D.C. Electrical Apparatus on Regular A.C. Lines—Equipped with Full-Wave Dry Disc-Type Rectifier, assuring noiseless, interference-free operation and extreme long life and reliability.

MAY ALSO BE USED AS A BATTERY CHARGER

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By every test ATR Auto-Radio Vibrators are best! . . . and feature Ceramic Stack Spacers, Instant Starting, Large Oversized Tungsten Contacts, Perforated Reed, plus Highest Precision Construction and Workmanship and Quiet Operation!

There is an ATR VIBRATOR for every make of car!

Ask your distributor for ATR's Low Priced type 1400, 6 volt 4-prong Vibrator; and 1843, 12 volt 3-prong; or 1840, 12 volt 4-prong Vibrator. **THE WORLD'S FINEST!**

There is a trim plate kit for YOUR CAR!



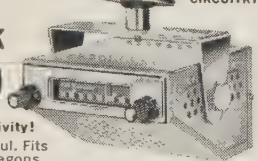
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KARADIO

Vibrator-Operated with Tone Control

ATR KARADIO . . . is ideal for small import cars or compact American cars! Unit is completely self-contained—extremely compact! Powerful 8-tube performance provides remarkable freedom from engine, static, and road noises. The ATR Customized Karadio comes complete with speaker and ready to install. Can be mounted in-dash or under-dash—wherever space permits! No polarity problem. Neutral Gray-Tan, baked enamel finish. Overall size, 7" deep, 4" high, and 6½" wide. Shipping weight, radio set, 7 lbs.
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Airplane Style Overhead Mounting under Cab Roof

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Excellent Tone, Volume, and Sensitivity!

Compact, yet powerful. Fits all trucks, station wagons, most cars and boats. Just drill a ⅝ inch hole in roof and suspend the one-piece unit (aerial, chassis and speaker) in minutes. Watertight mounting assembly holds antenna upright. Yoke-type bracket lets you tilt radio to any angle.

Extra-sensitive radio has 6 tubes (2 double-purpose), over-size Alnico 5 PM speaker for full, rich tone. Big, easy-to-read illuminated dial. Fingertip tuning control. Volume and tone controls. 33-in. stainless steel antenna. Neutral gray-tan enameled metal cabinet, 7 x 6½ x 4 in. high over-all. Shipping weight 10½ lbs.
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Professional Group Meetings

(Continued from page 98A)

Los Angeles—March 21

"Special 6-Channel FM/FM Telemetry System Featuring 2000-Cycle Reproduction on each Channel," J. Kauke, Kauke and Co., Santa Monica, Calif.

Los Angeles—February 21

"Digilock and FM/FM Telemetry," R. M. Jaffe, Space Electronics Corp., Glendale, Calif.

"Circuit Design and Packaging for Airborne Digital Instrumentation System," D. W. Boensel, Space Electronics Corp., Glendale, Calif.

Los Angeles—January 17

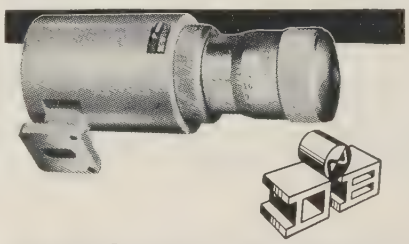
"PCM RF System for Boeing Minuteman Program," D. W. Lang, United Electrodynamics, Inc.

"A Building Block Approach to an Optimum Space Vehicle Attitude Control System," H. C. Beck and W. D. DeViney, North American Aviation, Downey, Calif.

Los Angeles—November 15

"Predetection Recording Techniques," S. Simmons, Pacific Missile Range, Point Mugu, Calif.

"Solid State FM/FM Telemetry," D. Bredon, Convair, Pomona, Calif.



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Vehicular Communications

Detroit—April 26

"Spectrum Analysis of Intermodulation and Interference Problems," E. Feldman, Panoramic Radio Products Co., Mount Vernon, N. Y

Los Angeles—April 20

"A New Approach to Frequency and Deviation Measurements for Mobile Communications," R. T. Cushman, Cushman Electronics Co., Sunnyvale, Calif.

Membership

The following transfers and admissions have been approved and are now effective:

Transfer to Senior Member

Adams, T. M., Arlington, Va.
Cerda, H. E., Santiago, Chile
Decker, E. E., Dayton, Ohio
Kagan, C. A. R., Princeton, N. J.
Krantz, C. H., Santa Monica, Calif.
Peterson, L. P., Omaha, Neb.
Prise, W. J., San Francisco, Calif.
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Utt, O. L., Monroeville, Pa.
Vieth, W. G., Harrington Park, N. J.
Witsiepe, R. E., Seattle, Wash.

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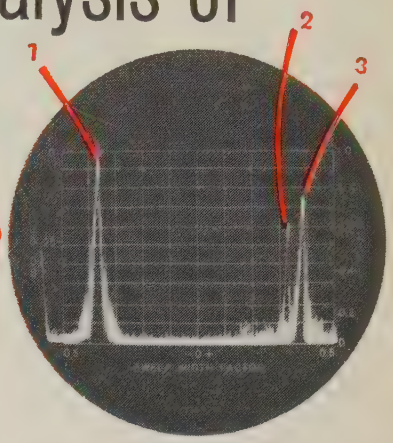
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Ashwell, J. R., Orlando, Fla.
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Kanner, L., Redwood City, Calif.

(Continued on page 108A)

PANORAMIC PANADAPTORS give you continuous visual spectrum analysis of communications signals



Interference analysis with Model SA-8b Panadaptor. Sidebands from AM channel #3 is seen to spill into band occupied by intermittent CW channel #2.

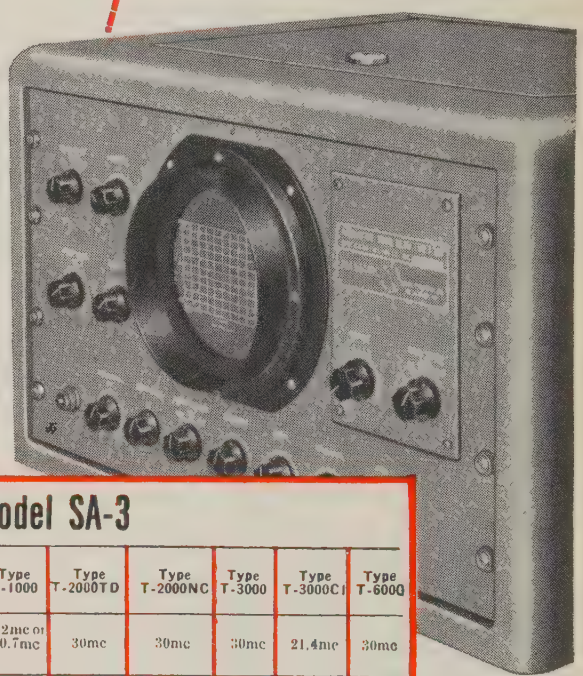
- **Detecting and investigating interference caused by splatter, harmonics, r.f. parasitics and multipath transmissions.**
- **Tuning aid for telemetry and SSB signals.**
- **Rapidly locating and identifying intermittent and irregular transmissions.**
- **Spotting inadvertent off-frequency transmissions.**
- **Band occupancy studies.**

Operating in conjunction with a communications receiver, the Panadaptor automatically scans the band around the frequency to which the receiver is tuned. Scan is adjustable from full sweep width capacity for observing over-all band to reduced sweep widths for detailed narrow band signal analysis.

Panoramic Panadaptors are available in two models and 14 types, to operate with RF, VHF and UHF receivers having standard IFs. Also available are specially designed Panadaptors for use with receivers with non-standard IFs or other unusual properties.

PANORAMIC'S PANADAPTOR MODEL SA-8b is a professional-quality spectrum analyzer designed for convenience and exceptional versatility. Adjustable sweep width, sweep rate and IF bandwith controls provide for optimum frequency resolution. Log, linear and power amplitude scales are precisely calibrated on a long persistence 5" CRT.

PANORAMIC'S PANADAPTOR MODEL SA-3 is a rugged, compact, easy to operate unit with a 3" CRT. Only three controls are needed—sweep width, gain and center frequency. Cabinet or rack mounting optional.



	Model SA-8b				Model SA-3									
	Type T-100	Type T-200	Type T-1000	Type T-10,000	Type T-50	Type T-100	Type T-200	Type T-1000	Type T-1000	Type T-2000TD	Type T-2000NC	Type T-3000	Type T-3000CI	Type T-6000
For receivers with IF	455kc or 500kc	455kc	5.25mc	30mc	455kc	455kc or 500kc	455kc	5.25mc	10.2mc or 10.7mc	30mc	30mc	30mc	21.4mc	30mc
Sweep Width	0-100kc	0-200kc	0-1mc	0-10mc	0-50kc	0-100kc	0-200kc	0-1mc	0-1mc	0-2mc	0-2mc	0-3mc	0-3mc	0-6mc
Direct Sensitivity*	1000μv	2000μv	2000μv	150μv	200μv	200μv	200μv	200μv	200μv	500μv	10μv	1mv	50μv	10mv
Sweep Rate	Sweep may be synch'd externally or to power line or free running.				30 sweeps per second, line synchronized. (25 sweeps/sec with 50-cps power line.)									
Amplitude Scales	Linear (calibrated from 0 to 1.0). Logarithmic (from 0 db to −40 db). Power.				Nominally linear									
Resolution Capabilities. Depends upon sweep rate and sweep width.	50cps to 4kc Variable	50cps to 4kc Variable	200cps to 10kc Variable	9kc to 80kc Variable	At maximum sweep width									
					2.5kc	3.4kc	4.4kc	11kc	11kc	20kc	20kc	25kc	25kc	50kc
					Approximately 20% improvement at 20% of full sweep width.									

* Direct sensitivity (Model SA-8b) is the maximum voltage at the center frequency required for a full scale deflection on the linear amplitude scale. Direct sensitivity (Model SA-3) is the maximum voltage at the center frequency required for ¼ inch deflection.

Panadaptors are available for most receivers. For best over-all response, the receiver type should be mentioned when inquiring about Panadaptors.

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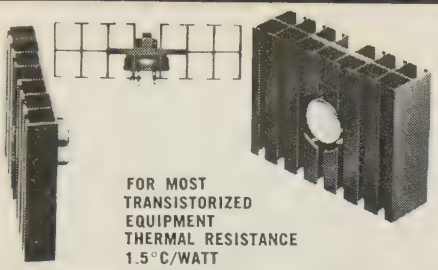
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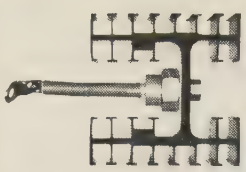
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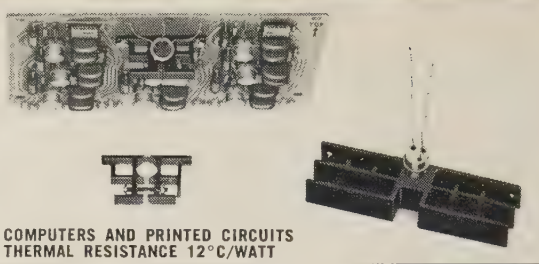
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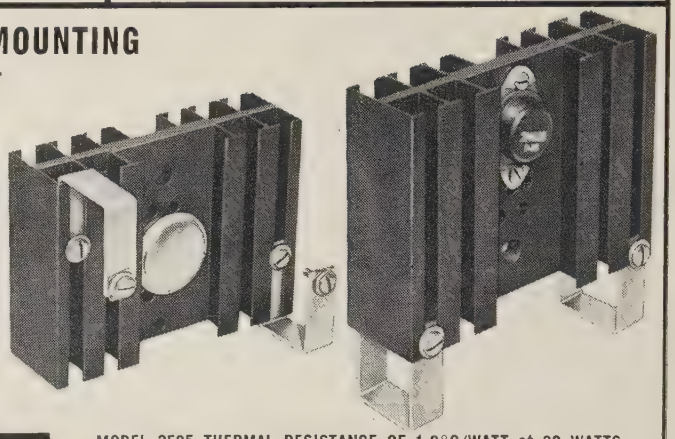
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The aluminum brackets may have both legs inserted between fins of heat sink and secured by speed nuts for mounting to horizontal chassis. Inserting and securing just one leg of each bracket to the heat sink, the other bracket leg can be used for mounting to vertical chassis.

The speed nuts may also be mounted directly on heat sink for direct mounting to a vertical chassis.

The patented fin design of Astro Dynamics heat sinks is highly efficient because it combines more surface area with *optimum free air flow!*



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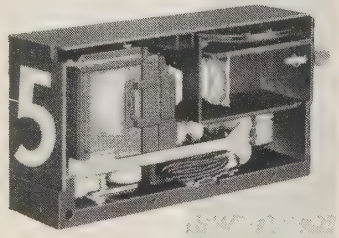
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(Continued on page 110A)



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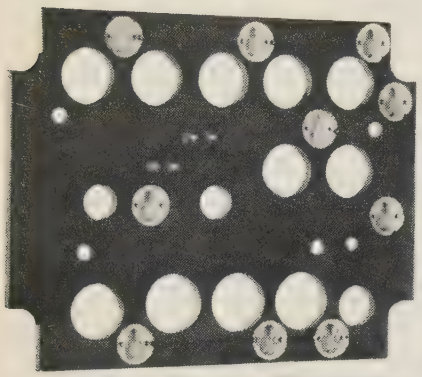
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OUTPUTS	Local oscillator phase change for strip-chart recording
	100 kc, 10 kc, and 1 kc derived from local oscillator
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(Continued from page 110A)

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Guild, R. F., Biloxi, Miss.
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Hall, P. D., East Meadow, L. I., N. Y.
Hansen, R. F., Biloxi, Miss.
Harper, A. L., El Paso, Tex.
Hernandez, J. D., Bogota, Columbia
Holt, L. A., Syracuse, N. Y.
Imboldi, E., Nutley, N. J.
Johnsen, D. A., Santa Ana, Calif.
Kalbreier, W. C., Chicago, Ill.
Kanter, M., Rehovoth, Israel
Kellogg, J. R., Placentia, Calif.
Kessler, S., Miami, Fla.
King, J. C., Framingham, Mass.
Kovacs, J. J., Blue Bell, Pa.
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Kurta, J. M., Brooklyn, N. Y.
Leone, T. D., Upper Darby, Pa.
Lipson, A. S., Willow Grove, Pa.
Lloyd, E. E., Temple City, Calif.
Loof, L., Los Angeles, Calif.
Lucas, R. A., Chicago, Ill.
Luckett, C. D., Biloxi, Miss.
MacCullough, T. B., Elmhurst, Ill.
Mangum, W. T., Los Angeles, Calif.
Martin, G. N., Mobile, Ala.
Martin, J. J., Fort Knox, Ky.
Michaelis, T., Washington, D. C.
Milewski, V. J., Glen Burnie, Md.
Moffitt, J. M., Gulfport, Miss.
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Moyer, C. P., Reading, Pa.
Nelson, J. E., Gardena, Calif.
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Norman, R. L., Keesler AFB, Miss.
O'Donnell, D. J., Oak Lawn, Ill.
Oliver, D. A., Nanaimo, B.C., Canada
Parlas, L. G., Burlington, Vt.
Passmore, D. A., Keesler, AFB, Miss.
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Price, T. E., Bangor, N. Wales, England
Rayhill, E. L., Grand Island, N. Y.
Rose, R. F., Council Bluffs, Iowa
Roseberry, R. T., Oak Ridge, Tenn.
Rosson, W. W., Cocoa Beach, Fla.
Sanders, C. H., Staten Island, N. Y.
Santoro, P. J., Schenectady, N. Y.
Scarborough, C. B., Belton, Mo.
Scheirer, D. A., Yorkton, Sask., Canada
Schliebener, G. K., Ottawa, Ont., Canada
Singer, L. K., Utica, N. Y.
Skinner, M. W., Citrus Heights, Calif.
Smith, G. D., Asheboro, N. C.
Some, N. M., Haddonfield, N. J.
Sproul, A. E., Jr., New York, N. Y.
Stacy, R. W., Columbus, Ohio
Stearns, J. R., Los Angeles, Calif.
Stegall, M. D., Richardson, Tex.
Steinman, D. J., Chicago, Ill.
Sullivan, R. D., Lake Charles, La.
Swenns, R. L., Richmond, B.C., Canada
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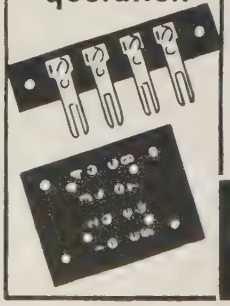
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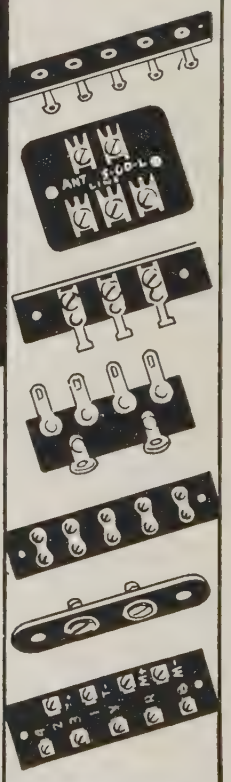


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Standard couplers for 3⅛" and larger coaxial lines are suitable for any power level and coupling ratio up to four watts coupler output, couplers for smaller lines are limited to one watt output. Waveguide couplers for 1½" x 3" and larger waveguide provide up to 2 watts output, couplers for smaller guide are limited to one watt.

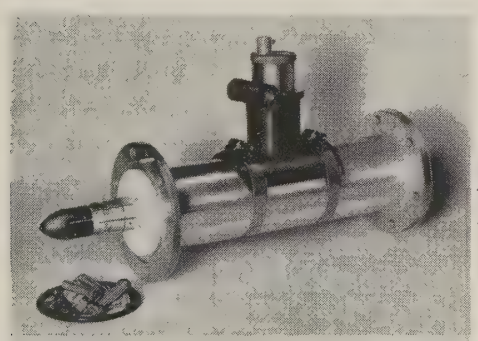
When a d-c output is required, a crystal detector can be supplied for direct attachment to the output jack. A unit comprising a d-c microammeter, reversing and range switches, and variable resistors for calibration is also available.

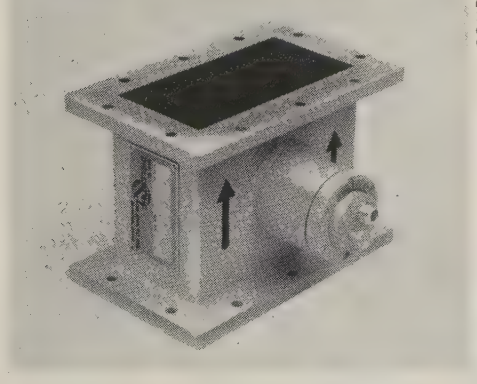
The VSWR caused by a coupler is small, and a direct function of penetration (coupling). At very high coupling ratios, the perturbation is almost unreadable. At maximum recommended coupling, VSWR is less than 1.03.

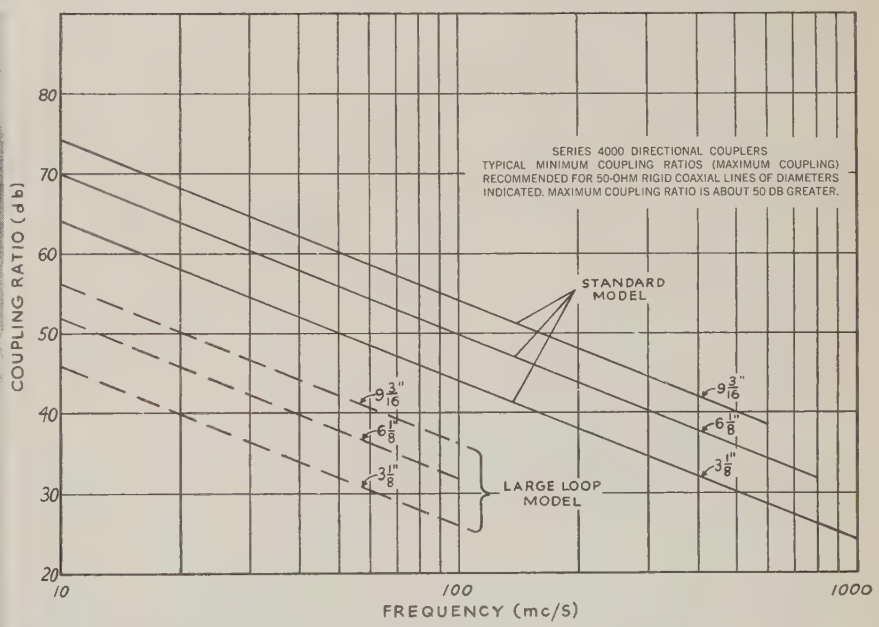
Directivity of standard models is not less than 30 db. On special order, models having a directivity of not less than 40 db will be supplied. The range of coupling ratio is roughly 30 to 80 db, depending on model and frequency.

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Section Meetings

ALAMOGORDO-HOLLOMAN

"Cosmic Radiation Experiments at Space Equivalent Altitudes," D. J. Corkhill, USAF. 4/25/61.

ANCHORAGE

"Government Communications in Alaska," H. L. Nestlerode, ALCOM. 3/6/61.

"460 Megacycle Path Tests in Alaska," R. E. Hutchinson, Communications Engrg., Inc.; "Why Transistors"—slides and tape commentary. 4/3/61.

ATLANTA

"Electronic Digital Computers and Their Uses," W. F. Atchison, Rich Computer Center; Tour of Center. 4/28/61.

BALTIMORE

Tour of Station WMAR-TV, WBAL-TV, and WJZ-TV. 4/10/61.

"Traffic Problems in the United States and Europe," H. A. Barnes, City of Baltimore. 5/6/61.

BAY OF QUINTE

"Electronic Control of Automobiles," J. B. Bidwell, GM Corp. 4/19/61.

BEAUMONT-PORT ARTHUR

"How to Select your Hi-fidelity System," A. M. Sitkoff, Sterling Electronics. 5/2/61.

BINGHAMTON

"Present State of the Art & Projected Trends in Semiconductors," 5/8/61.
Moderator—D. R. Weisser, IBM
Panel —Willis Adcock, Texas Insts.
H. M. Sullivan, GE
T. A. Lonso, Sylvania

CEDAR RAPIDS

Election of Officers. 1/21/61.

"Gyros for Space Application," J. K. Olson, Minneapolis-Honeywell Regulator Co.; Film: "Turbocopter Odyssey," by Sikorsky Aircraft Div. of United Aircraft Corp. 2/15/61.

"Thin Deposited Magnetic Films," A. Pohm, ISU; Discussion of Graduate & Undergraduate Programs, A. Pohm, ISU. 3/22/61.

"The Titan ICBM Program," R. M. Ringeon, The Martin Co. 4/19/61.

CENTRAL FLORIDA

"Molecular Electronics," S. Skinner, Westinghouse. 4/20/61.

CENTRAL PENNSYLVANIA

"Instrumentation for Rocket & Satellite Research," R. E. Prenatt, APG; "Special Electronics for Rocket & Satellite Research," K. H. Patterson, APG. 1/17/61.

"Watching the Moons Go By," D. C. Whitmarsh, Pa. State Univ. 4/18/61.

"Region IV IRE Activities," A. B. Bereskin, Regional Director; "Thermoplastic Recording," H. L. Lester, GE Co.; joint meeting with Emporium & Williamsport Sections. 5/16/61.

CINCINNATI

The 15th Annual Spring Technical Conference on Electronic Data Processing & Space Technology; in conjunction with The American Rocket Society. 4/12–13/61.

COLOMBIA

"Radio-Link Brasilia-Rio de Janeiro," G. Ward, RCA. 3/15/61.

DALLAS

"Evolution of the Application of Circuit Theory in Industry," Gerald Luecke, Texas Instruments, Inc. 4/27/61.

"Twin Gyro Space Vehicle Controller," D. F. Sellers, Vought Electronics. 5/16/61.

DETROIT

Student Papers Competition; Presentation of Outstanding Student Awards. 4/20/61.

"New Methods of Power Generation—Their Present Status & Future Prospects," J. A. Hutcheson, Westinghouse; "One Package Assorted," Howard Hess, Wayne State Univ. 4/25/61.

EL PASO

"Atlas & Titan Missile Bases," Lt. Col. Kimble, U. S. Army Corps of Engrs. Joint meeting with Texas Society of Professional Engrs. 2/22/61.

"The Changing E. E. Curriculum, 1936–1961," Jim Young, New Mex. State Univ.; "The Student's Feeling About the E. E. Curriculum," E. E. student, New Mex. State Univ. Joint meeting with Las Cruces Subsection. 4/20/61.

EMPORIUM

"Technical Continuity From Research to Promotion," Herbert Trotter, Jr., GT&E. 4/18/61.

ERIE

"The Value Concept of Reliability," George M. Armour, GE. 1/24/61.

"Recent Developments in Stereo Sound," Robert Page, Elgin Labs. 3/16/61.

"Shock & Vibration Control in Electronic Applications by the Use of Damped Structures," R. P. Thorn, Lord Mfg. Co. 4/18/61.

FLORIDA WEST COAST

"Microelectronics," Dr. Feldman, Melpar, Inc. 4/12/61.

"Microelectronics," D. S. Dunovan, Sperry (Semiconductor Div.). 4/19/61.

"Microelectronics," V. J. DeFillipo, RCA. 4/26/61.

"Microelectronics," A. D. Evans, Texas Insts. 5/3/61.

"Microelectronics," Norman Doctor, Diamond Ordnance Fuze Labs. 5/10/61.

FORT WAYNE

The Engineer's Christmas Ball. 12/9/60.

"Conquest of Inner Space," J. B. Fisher, Magnavox Co.; Bell Labs Film: "Wave Behavior." 1/26/61.

"Opportunities Unlimited," C. S. Winters, GM Corp. 2/22/61.

"Merchandising Big Ticket Merchandise," J. J. Pusternak, Magnavox.; Bell Lab movie on crystals shown—"Structure of Crystals." 3/23/61.

FORT WORTH

"Conquest of Space," Dr. L. V. Berkner, IRE President. 4/18/61.

GAINESVILLE

"Stereophonic Systems," Paul Klipsch, Klipsch Associates. 5/8/61.

HAWAII

"Investigations of the Ionosphere Using Satellite Transmissions," R. E. Partridge, Univ. of Hawaii. 2/8/61.

"The Loran-C System: History & Development," R. D. Dean, US Coast Guard: "The Loran-C System: Technical discussion," Stanley Pickarski, US Coast Guard. 3/8/61.

"Tasi (Time-Assigned Speech Interpolation)," E. C. Schoen, Hawaiian Tele. Co. Joint meeting with AIEE. 4/13/61.

HOUSTON

"Impedance Characteristics of Logarithmically Periodic Antennas," F. D. Moore, Texas A & M College; "A Study of Avalanche Transistor Opera-

tion & Circuit Application," R. M. Lockerd, Rice Univ.; "Basic Theory & Operation of Magnetic Amplifiers," D. R. Barnhill, Univ. of Houston. 4/11/61.

"Principles & Applications of Electric Well Logging," Hubert Guyod, Mandrel Industries. 4/18/61.

"The Impact of Electronics on Future Living," Dr. L. V. Berkner, IRE President. 5/5/61.

INDIANAPOLIS

Student Award Presentation. 4/13/61.

ITALY

"Sviluppi dell'elettronica nel campo della medicina," R. L. McFarlan, past IRE President. 9/23/60.

"Raddrizzatori Controllati Al Silicio," F. W. Gutzwiller, Int'l. GE. 10/19/60.

"Oscilloscopi per la Visions di Fanomani ad Alte Frequenza," Barney Olivier, Hewlett Packard Co. 10/28/60.

ITHACA

"Perspective on Microminiaturization," S. R. Danko, V. J. Kublin, R. A. Gerhold, J. D. Meindl, US Army Signal Res. & Dev. Lab. 4/13/61.

KANSAS CITY

"Career Partnership," R. L. Hudson, Midwest Christian Counseling Ctr.; Election of Officers. 5/2/61.

KITCHENER-WATERLOO

"Nuclear Reactor Instrumentation," G. G. Lennox, Atomic Energy of Canada Ltd.; Election of Officers. 4/17/61.

LAS VEGAS

"Discoverer Satellite Program," A. J. Steele, Lockheed Aircraft Corp.; Installation of new Officers. 5/1/61.

LONDON (Canada)

Tour of R & C School—F. L. Gillean, RCAF; Election of Officers. 5/15/61.

LITTLE ROCK

"Project Echo," Film presentation on the joint effort of BTL & JPL in placing the "Echo" satellite in orbit. 4/10/61.

"Electronic Switching of Telephone Calls," Paul Fleming, Jr., Automatic Elec. Labs. 5/8/61.

LOS ANGELES

"Face of the Space Age." A. N. Curtiss, RCA; Joint meeting with San Fernando Valley Subsection. 4/12/61.

"Contributions of the Southern California Electronics Industry & The BUWEPS Activities to National Defense," F. L. Ashworth, USN; Joint meeting with Buenaventura Subsection. 5/5/61.

LUBBOCK

"Past, Present, and Future of IRE," Mr. John Byrne, Vice-President IRE, No. America; Election of Officers. 4/18/61.

MIAMI

"Chopper Amplification of Low Level DC Signals," D. A. Robinson, Airpax Electronics. 4/27/61.

NORTH CAROLINA

"Isotope Uses in Industry," R. L. Eely, H. Richter, Res. Triangle Inst. 5/19/61.

NORTHERN ALBERTA

Student Papers Night. 3/21/61.

NORTHERN NEW JERSEY

"Thermoelectric Conversion," F. D. Rosi, RCA. 4/12/61.

OMAHA-LINCOLN

Annual business meeting; Nomination of 1961–62 Section Officers. 5/5/61.

Tour of Good-All Elec. & Mfg. Co. 5/13/61.

(Continued on page 116A)

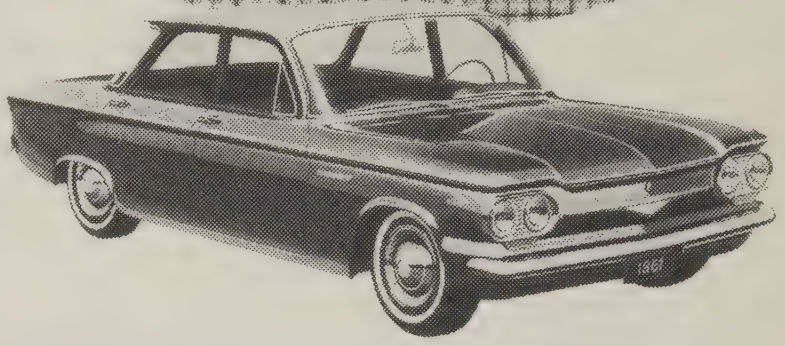
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ARMED FORCES COMMUNICATIONS AND ELECTRONICS ASSOCIATION

BPA

Section Meetings

(Continued from page 115A)

PHILADELPHIA

"The Romance of Engineering," G. M. Hopper, Remington Rand Univac Res. Ctr.; Joint AIEE annual meeting and Student Night. 4/15/61.

PRINCETON

"Bionics," J. E. Steele, USAF; Election of Officers. 4/13/61.

REGINA

Tour of Interprovincial Steel Co. 3/6/61.

Films: "Tour of Plant"—"Electronic News," by Hughes Aircraft Corp. 4/3/61.

"Antennas for Microwave Systems," R. P. Matthews, Andrew Antenna Corp., Ltd. 4/20/61.

SACRAMENTO

"Analog Computers, Their Use & Operations," Jack Cook, RCA; "Space Vehicle—Re-entry Problems," George Story, USAF. 3/16/61.

"Noise & Human Reaction," Louis Bourget, Res. Lab. Div. of Highways, State of Calif. 4/14/61.

ST. LOUIS

"Radio Communication Via Satellites," J. L. Glaser, Bell Tele. Labs. 3/15/61.

"Propagation Characteristics of Ionized Media," Henri Hodara, The Hallicrafters Co. 4/18/61.

SAN ANTONIO-AUSTIN

"Impression of Soviet Semiconductor Research," R. L. Petritz, Texas Instruments. 4/27/61.

SCHENECTADY

"Navigation Theory for Interplanetary Flight," Richard Battin, MIT. 4/25/61.

SEATTLE

"Theory & Design of Lightweight Inertial Navigation Systems," H. J. Smead, Litton Industries. 3/19/61.

Student Paper Contest. 4/13/61.

Annual Banquet—"Coexistence of the Old and the New in Japan," Katsunori Shimada, Univ. of Washington. 5/11/61.

SHREVEPORT

"Nike-Zeus Missile System," T. B. Mosely, Continental Electronics Mfg. Co.; Election of Officers. 5/2/61.

SOUTH BEND-MISHAWAKA

"Compatible Color Television," John Wentworth, RCA; Election of Officers. 3/30/61.

Presentation of Student Awards. 4/20/61.

TOLEDO

"Electronic Techniques in Telephone Switching," W. Keister, Bell Tele. Labs., Inc. 3/28/61.

"Automatic Controls & Computers," V. V. Tivy, Foxboro Co. 4/12/61.

Tour of Toledo Express Airport. 5/11/61.

TORONTO

"Controlling Traffic In Metropolitan Toronto with an Electronic Computer," L. Casciato, KCS Ltd.; Election of Officers. 4/24/61.

TWIN CITIES

"Solid State Devices," Robert Borschard, Motorola Semiconductor Div. 3/20/61.

"Using Objectives to Plan Your Life & Career," D. C. Basil, Univ. of Minn.; Student Awards. 4/20/61.

(Continued on page 118A)



How to shrink a filter!

Magnetics Inc. "120" solves the problem of core size vs. inductance in miniaturized circuits

Trying to squeeze high core inductance into a small space for use in miniaturized resonance, filter, audio, or carrier frequency circuits usually ends in a compromise. You either force more out of a smaller core, or you use a larger one. Not so, however, if you're familiar with the Magnetics Inc. "120."

This molybdenum permalloy core has a .655 inch outer diameter—is just between the .500 and the .800 inch core you may be using. What makes this little fellow unique is its inductance per 1,000 turns . . . higher than either of its neighbors, whether 60, 125 or 160 permeabilities.

Note, too, that like all Magnetics Inc. powder cores, the "120" is performance-proved and rated within realistic inductance limits. All permeabilities are available from stock now. What's more, the 125 permeability core is inductance stabilized within $\pm 0.1\%$ from 0° to 55°C.

More information on this and other cores in the Magnetics Inc. line is contained in design bulletin PC-203 R. It's yours by writing *Magnetics Inc., Department P-91, Butler, Pennsylvania.*

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new! .05% accurate Miniature DC Potentiometer!



Model PC *

PocketPot

Precision DC measuring potentiometer with self-contained galvanometer and battery operated standardization circuit. Direct "in line" readout. Additional voltage and current ranges can be obtained by using it in combination with the Model PC-1, a switch controlled, .05% accurate "plug in" unit of the same size.

Additional Specifications

ACCURACY: ± .05% of reading or ± .5 mv., whichever is greater.

RANGES: 0–5.099 v; when used with PC-1, 0–500 v. and 1 amp.

RESOLUTION: Continuous. 1 mv. divisions on slide wire.

SENSITIVITY: Infinite resistance at null. When used with PC-1, 2,000 Ω/v.

SIZE: 9" x 4¼" x 1¾".

WEIGHT: 3 lbs.

PRICE: Model PC, $325.00; Model PC-1, $125.00.

*Copyright U.S.A. Patent Applied for

SENSITIVE RESEARCH INSTRUMENT CORPORATION

NEW ROCHELLE, N.Y.

Section Meetings

(Continued from page 116A)

VANCOUVER

"New Concepts in Mobile Radio Design," M. A. Robbins, Canadian Marconi Co. 3/29/61.

"The Engineering Aspects of Developing & Commissioning a New TV Station," E. Rose, Channel 8 TV. Joint meeting with AIEE. 4/10/61.

Field Trip Tour of Facilities at Pacific Naval Labs. Esquimalt, B. C., H. H. A. Davidson, Pacific Naval Labs. 4/22/61.

"Hands Across the Pacific," D. M. Myers, Univ. of British Columbia. 5/15/61.

VIRGINIA

"Russia"—Illustrated with Slides, J. G. Hutton, GE Co. 4/14/61.

"The Tactical Air Command Story," G. L. Buttes, R. J. Spence, USAF. Joint meeting with Central Virginia Engineers Club. 4/21/61.

WASHINGTON

"The Optical Maser," D. F. Nelson, Bell Tele. Labs. 4/10/61.

"Defense Communications—A Technological & Management Problem," J. R. McNitt, USAF. 5/8/61.

WINNIPEG

"Two Hop—450 Mc. Diffraction Plus Scatter System for Telephone Service," Chris Gillespie, Manitoba Tele. System. 2/22/61.

"Radar Speed Check System," Corporal Thompson, RCMP. 3/14/61.

"Antenna Design," R. P. Matthews, Andrews Antenna Corp. of Canada Ltd. 4/21/61.

WESTERN MASSACHUSETTS

"Looking & Listening in Space," R. E. Anderson, Radio Optical Observatory. 5/17/61.

SUBSECTIONS

BUENAVENTURA

"Do It Yourself Thinking for an Age of Togetherness," Bernard Benson, Benson-Lerner Corp. 4/12/61.

LEHIGH VALLEY

"High Speed X-Band Solid State Switch," S. A. Robinson, Russell Wright, Philco Corp.; Election of Officers. 4/26/61.

MERRIMACK VALLEY

"Atomic Power in New England," J. W. Lebourveau, Yankee Atomic Power Co. 3/20/61.

"Microelectronic Developments," George Henderson, CBS Labs.; Election of Officers. 4/17/61.

NASHVILLE

Executive Meeting. 3/14/61.

"What Can Electronics Do for Speech & Hearing," L. H. Montgomery, Bill Wilkerson Speech & Hearing Ctr., Vanderbilt Univ. 5/17/61.

NEW HAMPSHIRE

"Micro Modules in Avionics," Gerhard Sievers, RCA. 4/26/61.

ORANGE BELT

"Proximity Warning Systems," J. F. Byrne, IRE Vice-President, No. America; Election of Officers. 4/11/61.

PALM BEACH

"The US Coast Guard's New Aid to Navigation —The Loran C System," C. D. Maxwell, USCG. 4/18/61.

PANAMA CITY

Installation of Officers for 1961–1962. 4/25/61.

PASADENA

"The Los Angeles Automatic Traffic Control System," Robert Warr, Los Angeles Dept. of Traffic. 2/16/61.

"Air Ionization: Its Effect, Control & Measurement," W. D. Doran, U. S. Radium Corp. 3/16/61.

"Moonbounce Communications," Christian Clausen, Jet Propulsion Lab.; "Venus Radar Experiment," Walter Victor, Jet Propulsion Lab. 4/20/61.

PIKES PEAK

"Afghanistan," W. G. Worcester, Univ. of Colo. 4/12/61.

SANTA BARBARA

"Modern Infrared Techniques," A. H. Canada, Raytheon Co. 4/18/61.

WESTERN NORTH CAROLINA

"Ultrasonics in Industry," Eugene Neal, Jr., Pelton & Crane Co. 4/21/61.

IRE People

(Continued from page 60A)

Robert H. Sugarman (S'47–A'47–SM'54) has been named as head of the Signal Environment Section of AEL, Inc., Philadelphia, Pa. The section is responsible for the analysis, measurement, and control of equipment and operational radio frequency factors which contribute to systems performance degradation. This includes Radio Frequency Interference and electronic countermeasures as well as areas of interference reduction and anti-jamming.



R. H. SUGARMAN

During the past 12 years, he has been associated with the U. S. Army Signal Research and Development Laboratory at Fort Monmouth, N. J.

He was employed initially in the Development of Nuclear Radiation Detectors and Instrumentation. Since 1954 he has worked in the fields of Electronic Countermeasures and Interference Reduction, serving as Chief of the Vulnerability Branch and subsequently as Deputy Director of the Electromagnetic Equipment Division.

A Navy veteran, he was employed by Rutgers University, New Brunswick, N. J., from 1947 to 1948 as Project Engineer on the development of instrumentation to measure the atmospheric index of refraction.

He received the B.S. degree in Electrical Engineering from Newark College of Engineering, Newark, N. J., in 1945 and the M.S. degree in Electrical Engineering from the University of Pennsylvania, University Park, in 1948.

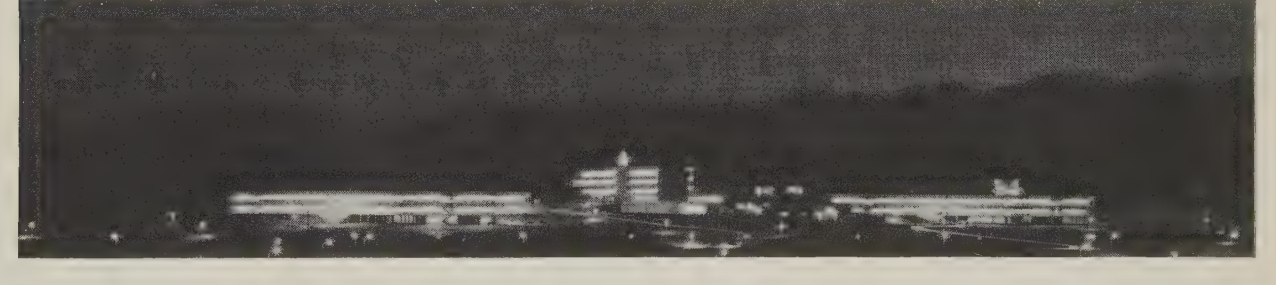
Mr. Sugarman is a member of the Armed Forces Communications and Electronic Association.

❖

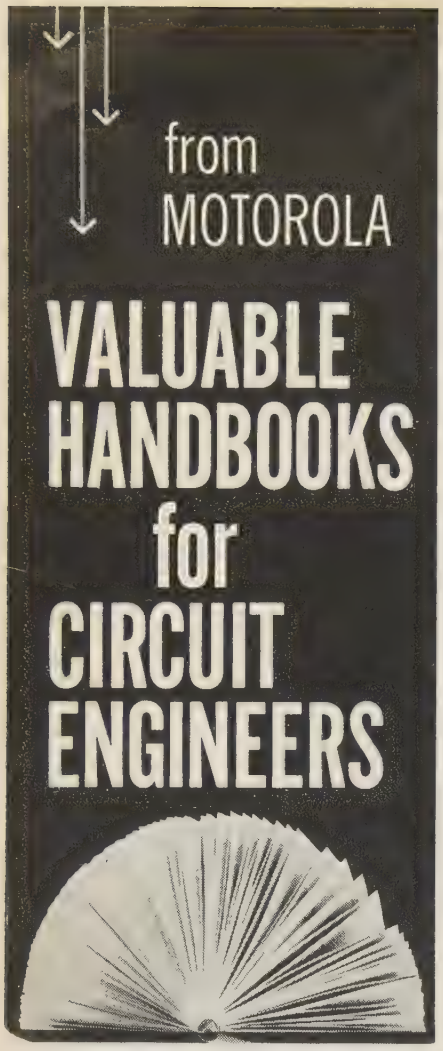
(Continued on page 120A)

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IRE People

(Continued from page 118A)

Microwave Associates, Inc., announces the appointment of **Dr. Meyer Gilden** (S'47–A'48–M'55) as Senior Engineer in the Electron Tube and Device Division. He will be engaged in plasma physics research and will report to Dr. L. Gould, Vice President in charge of the Electron Tube and Device Division.



M. GILDEN

His extensive background in research and development includes work in the Microwave Technique Subsection of General Electric's Microwave Laboratory in Palo Alto, Calif. His work at GE included microwave switching, using gas discharges and vacuum discharges, gas discharge phase shifters using slow wave modes, microwave filter problems, and shock tube instrumentation.

Prior to joining Microwave Associates, he was a Research Engineer in the Electromagnetics Laboratory at Stanford Research Institute in Menlo Park, Calif., where his principal activity was with parametric amplifiers.

He was also an assistant professor at the University of Illinois, Urbana, and worked with Dr. L. Goldstein in the Gaseous Electronics Laboratory.

He received the Bachelor's degree (1946) and the Master's degree (1948) in electrical engineering from the Illinois Institute of Technology, Chicago, and the Doctorate in electrical engineering from the University of Illinois in 1955.

He is a member of the American Physical Society, Sigma Xi, and Eta Kappa Nu.

❖

Marcellus B. McDavitt (M'46–SM'57), Director of Transmission Development of Bell Telephone Laboratories, has been elected a Vice President of the company, effective April 1, 1961. He will be in charge of apparatus development, design engineering, and quality assurance.



M. B. MCDAVITT

He began his Bell System career in 1925, in the development and research department of the American Telephone and Telegraph Company, and transferred with the department to Bell Laboratories in 1934. Since that time he has been associated with the development of switching and transmission systems for Bell System use. During World War II he specialized in military communications systems planning and later served as Director of the Bell Laboratories School for War Training. In 1952 he was named Director of Transmission Development.

A native of Texas, Mr. McDavitt received the E.E. degree from the University of Virginia, Charlottesville, in 1924, and the M.S. degree in electrical engineering from the Massachusetts Institute of Technology, Cambridge, in 1926. He is a Fellow of the AIEE.

❖

Daniel L. Whybark (M'55) has joined Eitel-McCullough, Inc., as a senior sales engineer, according to a recent announcement. He has been assigned to the company's Los Angeles, Calif., sales office. His sales territory will include Southern California, Arizona, and Southern Nevada.



D. L. WHYBARK

Before joining Eimac, Mr. Whybark was an applications engineer in the western states for Raytheon Manufacturing Company.

❖

Peter W. Hannan (S'49–A'49–M'55–SM'59) has been named to the position of consulting engineer at Wheeler Laboratories, Inc., a subsidiary of Hazeltine Corporation.



P. W. HANNAN

Best known for his invention of the polarization - twisting Cassegrain antenna, he has made widely-ranging contributions to the microwave field.

Mr. Hannan was graduated from the Stevens Institute of Technology, Hoboken, N. J., and received the Master's degree from the University of Pennsylvania, Philadelphia.

❖

Ray E. Homan (M'57) has been named District Sales Manager of the Redstone District Office of the General Electric Company's Heavy Military Electronics Department in Huntsville, Ala., according to a recent announcement.



R. E. HOMAN

In his new position he will be responsible for directing his department's field sales activities in the Redstone District. The Redstone District Office was opened in 1959 to provide marketing and engineering liaison service to U. S. Army and National Aeronautics and Space Administration customers in that area.

(Continued on page 123A)

The Highest Sensitivity
and the lowest noise.....

Advanced electronic research by Hitachi technicians has now resulted in the development of a superb frame grid type twin triode (6R-HH8) with excellent high gain and low noise characteristics. As a component of the tuner, the 6R-HH8 ensures an excellent picture with a remarkable degree of definition.

fig. 1 Gain characteristics

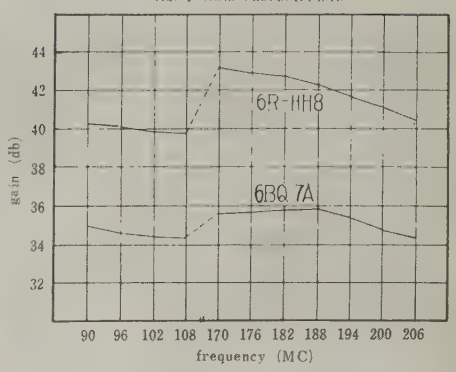
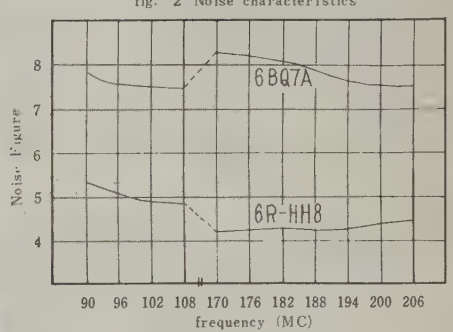
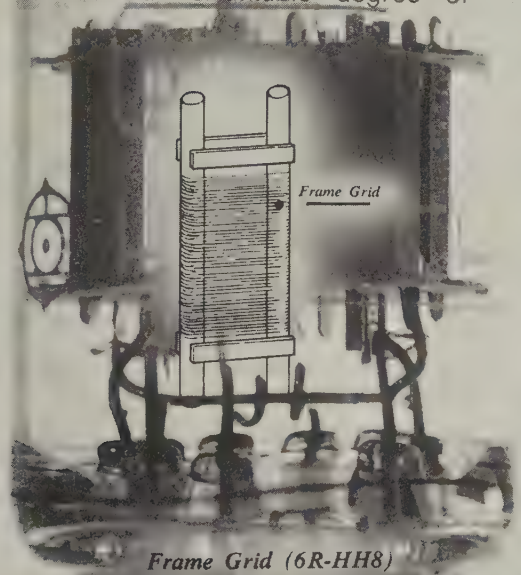


fig. 2 Noise characteristics





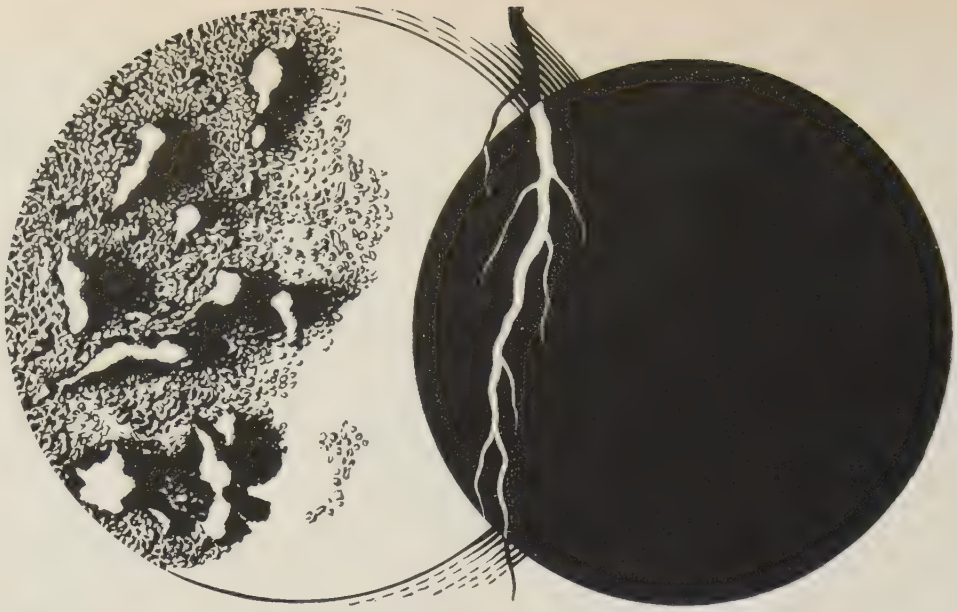
Frame Grid (6R-HH8)

Hitachi also produces other receiving tubes and components for television which, when used together with the new 6R-HH8, cannot fail to earn any maker a market reputation even better than he currently enjoys.



Automatic tube testing equipment

Hitachi, Ltd.
Tokyo Japan
Cable Address: "HITACHY" TOKYO



WHY SPY?

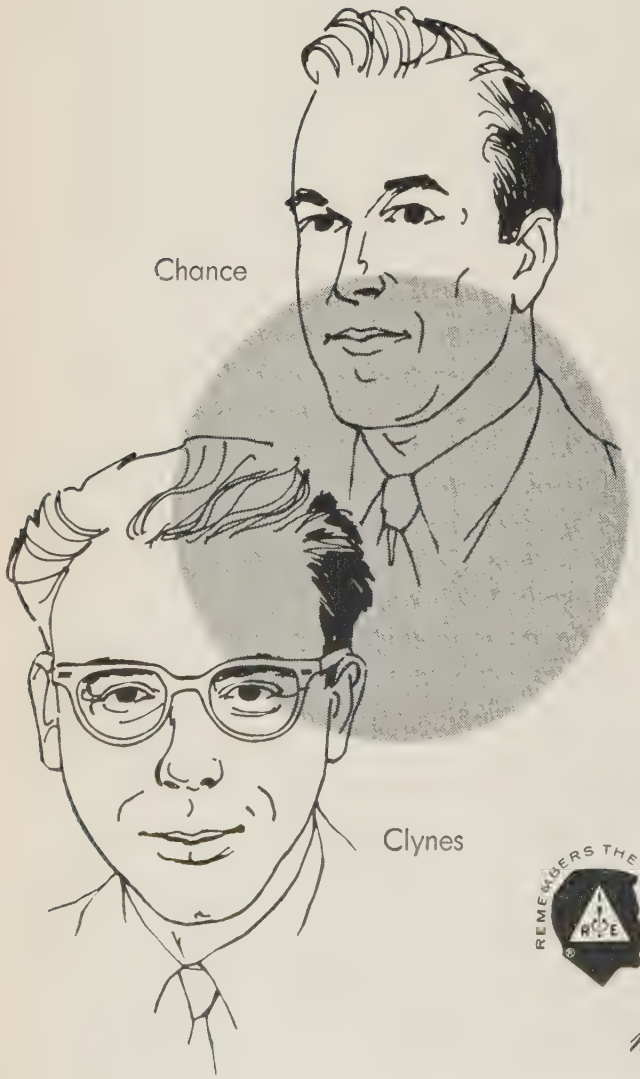
Secret Agent X defied detection for centuries. When he struck in past ages, men attributed death to many causes, never to him. In this century men became conscious of his existence. But no spyglass could find him; no telescope reveal his hideout; no microscope uncover his traces. Until . . .

With the coming of the electron microscope, the activities of Agent X are no longer secret. He's being watched at work in a hundred places — in cancer cells, or destroying man's body in countless different ways. Soon, counter measures will be devised.

Bio-medical research owes much to doctors and much to electronic engineers. Amongst these are thousands of highly-trained IRE members, a small but important section of the membership of the Institute of Radio Engineers. Their significant researches are published frequently in *Proceedings;* in this way they become available in America's continuing battle against disease.

Two IRE members are being honored this year for contributions in this field. To Britton Chance, of the University of Pennsylvania, goes the William J. Morlock Award for applying advanced electronic techniques in a long-term program of fundamental biological research. To Manfred Clynes, of Rockland State Hospital, Orangeburg, N. Y., goes the W.R.G. Baker Award for a paper on "Respiratory Control of Heart Rate: Laws Derived from Analog Computer Simulation."

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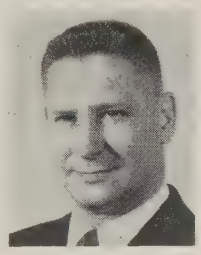
(Continued from page 120A)

He first joined the General Electric Company as a member of the Test Engineering Program in 1949, after receiving the Bachelor's degree in Industrial Engineering from the Massachusetts Institute of Technology, Cambridge. In 1951 he became associated with the Company's Control Engineering group in Schenectady, and then joined Laboratory Product Sales there. He joined the Communications and Navigation Sales Unit of General Electric Company's Light Military Electronics Department, Utica, N. Y., in 1954. He was with Navy Product Planning, where he was primarily concerned with antisubmarine warfare and naval defense, from 1959 until his present appointment.

Mr. Homan's military experience includes service with the U. S. Army Infantry and Ordnance Corps. He is a member of the Armed Forces Communications and Electronics Association.

❖

The appointment of **Edward W. Jervis, Jr.** (A'48–M'55–SM'59) as manager of the MOBIDIC (Mobile Digital Computer) program office of the Data Systems Operations of Sylvania Electric Products Inc., has been announced.



E. W. Jervis, Jr.

In his new capacity, he will direct all MOBIDIC computer projects. The MOBIDIC family of Computers, developed and produced under a series of U. S. Army Signal Corps contracts, represents the first general-purpose highspeed mobile data processing system ever developed for general military service.

The Data Systems Operations are a part of Sylvania Electronic Systems, a major division of the company, which has over-all responsibility for systems management of GT&E's major government projects.

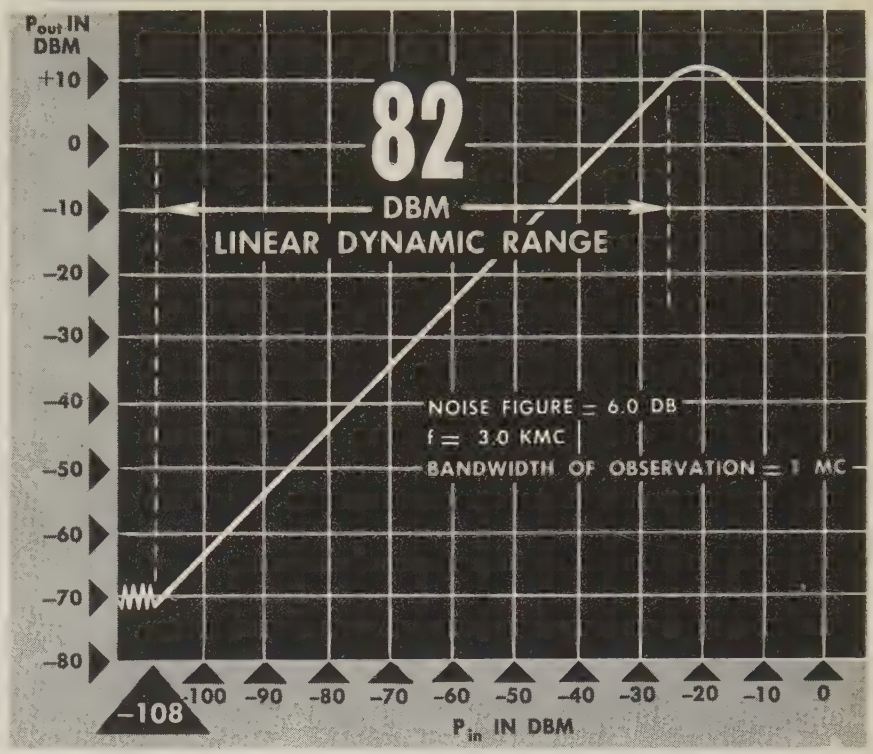
Mr. Jervis joined Sylvania Electronic Systems in 1956 as Supervisor of the Development Section, Development Department, of the division's Waltham Laboratories, Waltham, Mass. In 1958, he was transferred to the Data Systems Operations as manager of the computer development department, and the following year became MOBIDIC projects manager.

Prior to joining Sylvania, he was Chief Engineer of the Business Machines Division of the Electronics Corporation of America. A native of Somerville, Mass., and a graduate of Tufts College, Medford, Mass., he is a U. S. Navy veteran of World War II.

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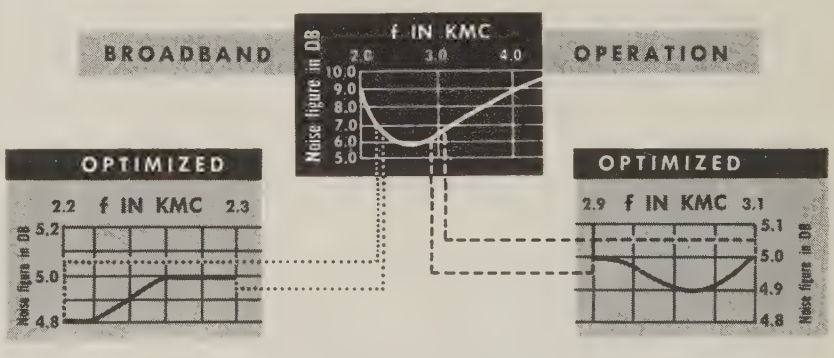
(Continued on page 124A)

Low-noise TWTs . . . wide dynamic range



Huggins low-noise traveling wave tubes provide 7 DBM minimum saturation P_{out} over major portions of octave bandwidths—coincident with low-noise performance. An example is the HA-70 characteristics shown above. The low noise figure plus high P_{out} results in the maximum degree of linear operation consistent with the present state of the TWT manufacturing art.

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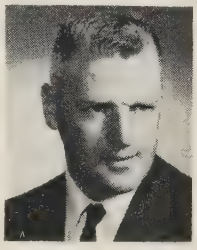
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IRE People

(Continued from page 123A)

Gordon B. Knoob (A'53–SM'56) has been appointed to the position of Staff Engineer in the Program Planning Department of the Western Center of Motorola's Military Electronics Division at Scottsdale, Ariz., it was recently announced.



G. B. KNOOB

In his new position he will be responsible for the development of new program and product areas in the field of aerospace activities.

He draws from 18 years experience in military electronics. Prior to his current assignment he managed the West Coast Regional marketing activities for Motorola's Military Division in Hollywood, Calif. His electronics career, following graduation from Pomona College, Claremont, Calif., with the B.A. degree in physics in 1942, includes four years as a member of the senior technical staff at the Motorola Systems Research Laboratory in Riverside, Calif.

Prior to joining Motorola he was engaged in engineering positions with the National Bureau of Standards/Naval Ordnance Laboratory at Corona, Calif., and the Naval Research Laboratory in Washington, D.C.

Mr. Knoob is a member of the Executive Committee of the Los Angeles Section of the IRE. From 1959–1960 he was Professional Group Coordinator for the Los Angeles Section, and from 1958–1959 he was Chairman of the IRE Professional Group on Military Electronics for the Los Angeles Section. Prior to this Chairmanship, he served as Vice Chairman of the PGMIL.

He is also a member of the Army Ordnance Association and a former member of the Armed Forces Communications and Electronics Association.

❖

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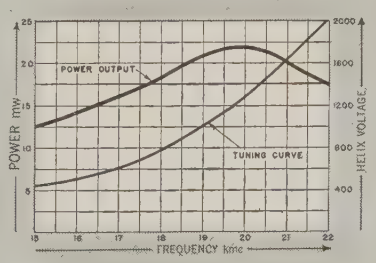
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OD 3.7-5.9	3.7-5.9	30-45
OD 4-8	4-8	10-70
OD 5.2-8.3	5.2-8.3	10-40
OD 6-11	7-11	10-40
OD 6-12	6-12	10-30
OD 7-13	8.2-12.4	10-15
OD 10-15	10-15.5	10-20
OD 12-18	12.4-18	10-25
OD 15-22	15-22	10-20

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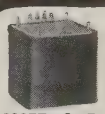
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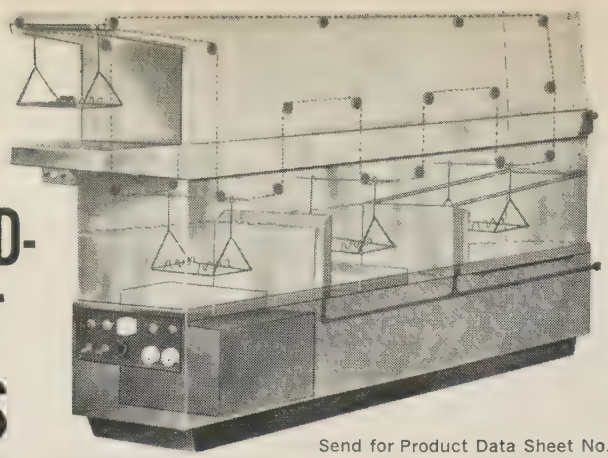


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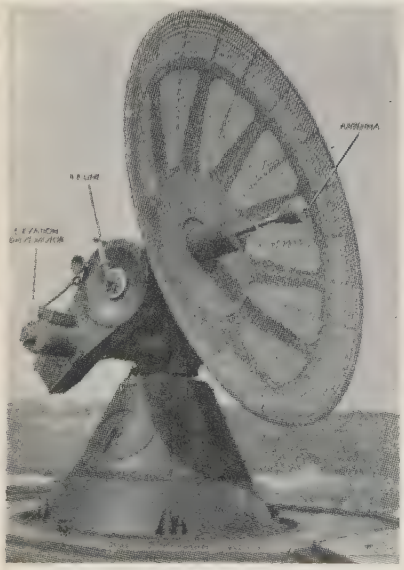
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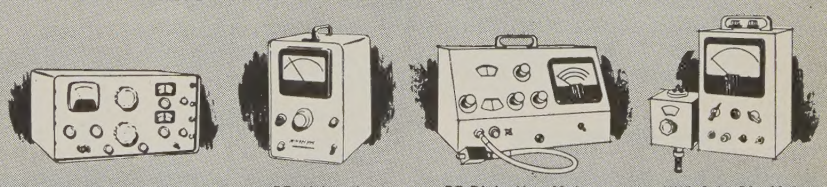
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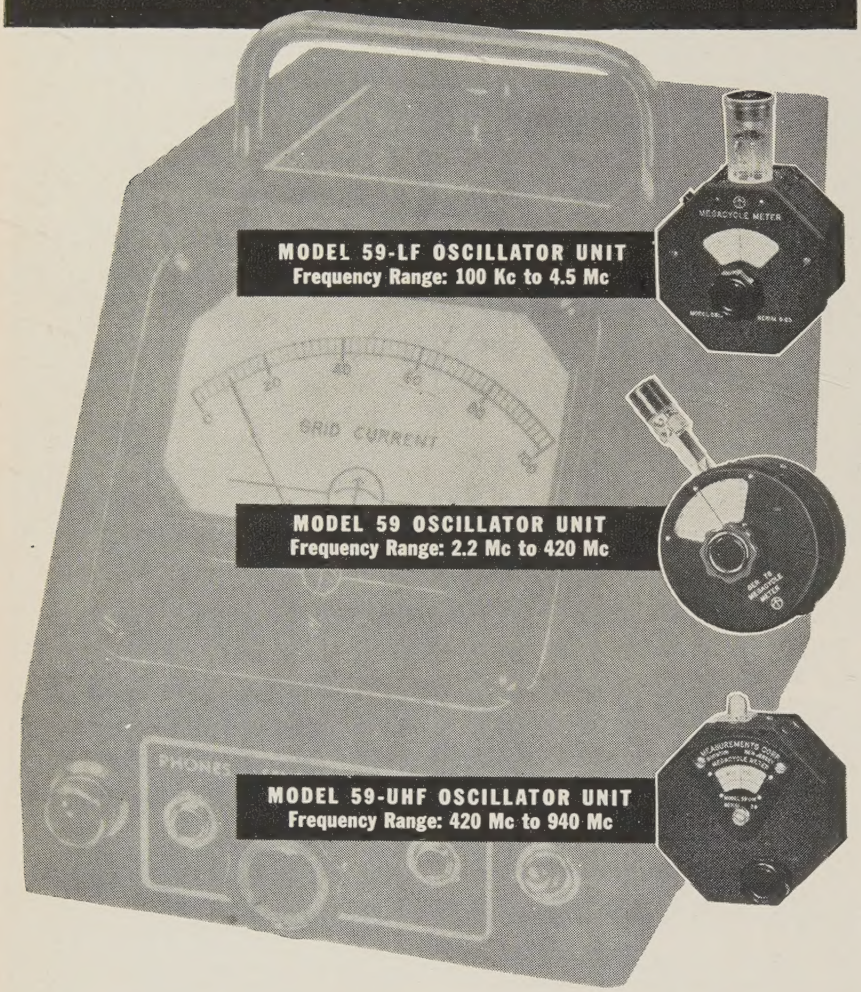


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0.1 Mc to 940.0 Mc



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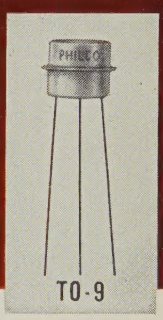
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Storage Temperature	−65 to +100°C
Collector Voltage, V_{CB}	−20 volts
Collector Voltage, V_{CES}	−20 volts
Collector Voltage, V_{CEO}	−15 volts
Collector Current, I_C	−100 ma
Total Device Dissipation @ 25°C	150 mw

ELECTRICAL CHARACTERISTICS (@ 25° C)

Characteristics	Conditions	Min.	Max.	
Collector Cutoff Current, I_{CBO}	V_{CB} = −5v		3	μa
DC Current Amplification Factor, h_{FE}	V_{CE} = −0.5v, I_C = −50 ma	35		
DC Current Amplification Factor, h_{FE}	V_{CE} = −0.5v, I_C = −10 ma	50	300	
Collector Saturation Voltage, $V_{CE\ (SAT)}$	I_C = −10 ma, I_B = −0.5 ma	.050	0.140	volt
Base Input Voltage, V_{BE}	I_C = −10 ma, I_B = −0.5 ma	0.25	0.35	volt
Hole Storage Factor, $K's$	I_B = −2.5 ma		100	nsec
Gain Bandwidth Product, f_T	V_{CE} = −10v, I_E = −6ma	150		mc

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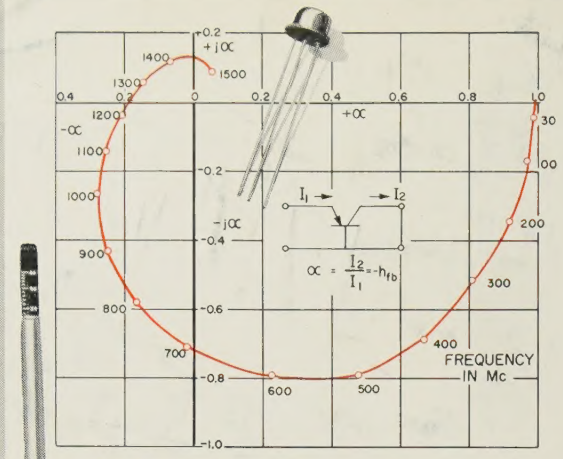
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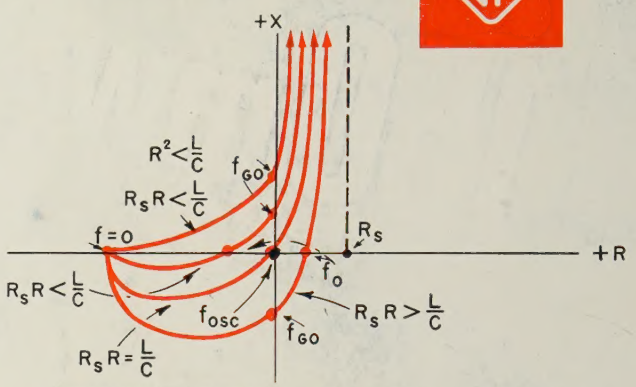
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α(-hfb) versus frequency for a diffused-base transistor, as measured with Type 1607-A Bridge.



Tunnel-diode impedance characteristics plotted to determine approximate values for the self-resonant and resistive cut-off frequencies.



Type 1607-A Transfer Function and Immittance Bridge . . . $1775

Measures every Characteristic of Semiconductor Devices from 25 to 1500 Mc

TRANSISTORS — h_{fb}, h_{fe}, h_{rb}, h_{ib}, h_{ob}, h_{oe} — all short-circuit admittance and open-circuit impedance parameters.

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- ★ **DIRECT-READING** for all measurements.
- ★ **BASIC ACCURACY** is 5%.
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